Fishery Data Series No. 10-44

Smolt Production, Adult Harvest, and Spawning Escapement of Coho Salmon from Nakwasina River in Southeast Alaska, 2006-2008

by

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and

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June 2010

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Between 2006 and 2008, a continuing coded wire tag (CWT) project for coho salmon *Oncorhynchus kisutch* in Nakwasina River near Sitka, Alaska was conducted to supplement a regionwide effort to assess the status of key coho salmon stocks in Southeast Alaska. During spring 2006, 10,644 coho salmon smolt ≥70 mm FL were captured in minnow traps, marked with an adipose finclip, given a CWT, and released. During spring 2007, 10,633 coho salmon smolt ≥65 mm FL were captured in minnow traps, marked with an adipose finclip, given a CWT, and released. The Chapman modification to the Petersen model was used to estimate smolt abundances at 37,785 in 2006 and 59,457 in 2007. Beach seines, gillnets, and hook-and-line gear were used to capture immigrant coho salmon each autumn in 2007 and 2008. In 2007 a Jolly-Seber open-population model, was used to estimate escapement at 1,000 fish. In 2008 a bracketed peak count was expanded to estimate escapement at 3,610 fish. Harvests of returning Nakwasina River coho in 2007 and 2008 were 1,013 and 1,247, estimated exploitations in marine fisheries were 50.3% and 25.7%, and marine survivals were 5.3% and 8.2%, respectively. Total runs (escapement plus harvest) for all coho bound for Nakwasina River were 2,013 in 2007 and 4,857 in 2008.

Key words: coho salmon, *Oncorhynchus kisutch*, Nakwasina River, harvest, troll fishery, sport fishery, migratory timing, return, exploitation rate, Jolly-Seber, marine survival, coded wire tag, mark-recapture experiment, spawning escapement, smolt abundance, Southeast Alaska, expansion factor, Petersen.

INTRODUCTION

Coho salmon *Oncorhynchus kisutch* produced by Nakwasina River and thousands of other coastal river systems in Southeast Alaska collectively support the region's mixed stock commercial troll and net fisheries along with freshwater and marine sport fisheries. The Alaska Department of Fish and Game (ADF&G) has conducted comprehensive coded wire tag (CWT) assessment projects on a long-term basis to evaluate the effects of Southeast Alaska fisheries on specific coho stocks native to streams in northern and inside areas of Southeast Alaska (Yanusz et al. 1999), but stock-specific information is more limited for outside, central, and southern areas. In order to represent all geographic areas, projects have recently been implemented for specific stocks, including the Unuk River in southern inside waters (Jones III et al. 1999; 2001a; 2001b;Weller et al. 2002; 2006; 2003), Slippery Creek in central waters (Beers 1999; 2003, and Chuck Creek in southern outside waters (McCurdy 2005, 2006a, b, 2008). Along the outer coast, the first comprehensive CWT program began at Ford Arm in 1982 and has continued through 2008 (Shaul and Crabtree 1998; Leon Shaul, personal communication, Alaska Department of Fish and Game, Division of Commercial Fisheries, Douglas). The Division of Sport Fish also conducted a CWT project to assess fishery impacts to Salmon Lake (near Sitka) coho salmon during the periods of 1983-1990, 1994-1995 (Schmidt 1996, and 2001-2005 (Tydingco et al. 2006; Tydingco et al. 2008).

Beginning in 1998 and continuing through 2008, the Division of Sport Fish has conducted a coho salmon CWT project in Nakwasina River (Figure 1) to supplement the regionwide effort to assess the status of key coho salmon stocks in central Southeast Alaska (Brookover et al. 2001, 2003; Tydingco 2003; 2005a; 2005b; 2006). Estimated smolt abundance in Nakwasina River between 1998 through 2005 ranged from 22,472 (SE = 1,660) in 2002 to 102,794 (SE = 15,255) in 1998. Estimated harvests of returning adults in 1999-2006 ranged from 604 fish (SE = 109) in 2003 to 1,983 (SE = 354) in 1999 (Table 1).

Table 1.–Numbers of smolt tagged, smolt abundance with resultant escapement, and harvest from the Nakwasina River 1998-2008.

Year	Smolt tagged	Smolt abundance estimate	Smolt SE	Adult Esc	Adult Esc SE	Harvest	Harvest SE	Survival	Exploitation	Fraction tagged(θ)	Stream survey peak count	Proportion of escapement estimate	Expansion factor
1998	9,980	102,794	15,255	-	-	-	-	-	-	-	653	-	
1999	3,971	47,571	6,402	-	-	1,983	354	-	-	0.095	291	-	
2000	10,120	45,677	2,669	2,000	261	1,219	213	6.80%	0.379	0.082	419	0.21	4.77
2001	10,381	43,630	2,660	2,992	510	1,439	155	9.70%	0.325	0.221	753	0.25	3.97
2002	5,686	22,472	1,660	3,141	661	731	109	9.80%	0.178	0.237	713	0.23	4.41
2003	15,762	55,424	4,023	2,063	233	604	109	11.90%	0.226	0.225	440	0.21	4.69
2004	9,771	47,573	3,039	3,867	937	1,645	178	9.90%	0.298	0.286	399	0.10	-
2005	12,989	64,164	3,105	3,539	817	1,798	226	11.20%	0.337	0.205	892	0.25	3.97
2006	10,644	37,785	2,579	5,698	749	1,416	158	11.00%	0.198	0.202	996	0.17	5.72
2007	10,633	59,457	4,975	1,000	220	1,013	131	5.30%	0.503	0.273	385	0.39	2.60
2008	8,708	-	-	3,610	-	1,247	174	8.20%	0.257	0.177	839	0.24	-
Averages	9,877	52,655	4,637	3,101	548.5	1,310	181	9.31%	0.300	0.200	616	0.23	4.30

OBJECTIVES

The objectives of this study were to: (1) estimate the number of coho salmon smolt leaving Nakwasina River in 2006 and 2007; (2) estimate the marine harvests of coho salmon from Nakwasina River stocks in 2007 and 2008 via recovery of CWTs applied in 2006 and 2007; (3) estimate spawning escapements in 2007 and 2008; and (4) define the relationship between the estimated escapements and peak foot survey counts.

ADF&G managers will be able to use the information obtained through this project, combined with that provided by other indicator systems, to assess the current status of wild coho salmon stocks within Southeast Alaska. Using this information, coho salmon stocks can be managed to provide appropriate levels of harvest and opportunity while preserving sustainability. In addition, as future levels of exploitation, escapement, smolt production, or marine survival conditions change, managers will be better prepared to understand the implications of these events and be better equipped to enact effective management strategies. This project will further define the relationship between estimated escapements (as derived from open population mark-recapture experiments) and peak foot survey counts. Expanding peak foot survey counts may provide a cost effective tool to track yearly escapements in lieu of mark-recapture experiments.

STUDY AREA

Nakwasina River is located on the outer coast of Baranof Island in Southeast Alaska (Figure 1). It is about 13 km long, and the anadromous portion ranges between 6 to 30 m wide and up to 3 m deep. It empties into Nakwasina Sound (57° 15’16.8”W/135° 20’41.5”N) about 23 km north of Sitka. Nakwasina River drains approximately 8,600 square hectares and is one of the larger river systems on Baranof Island. Average daily flow rates between 1976 and 1982 ranged between 100 ft^3/s to 1,200 ft^3/s. Maximum and minimum average daily flows during this time period ranged from a low of 22 ft^3/s to a high of 3,400 ft^3/s.

Nakwasina River is known locally for its freshwater sport fisheries for coho salmon and Dolly Varden *Salvelinus malma*. Because Nakwasina River is easily accessed by boat and supports one of the largest populations of coho salmon in Sitka Sound, it is one of the few rivers near Sitka that attracts freshwater sport fishing effort for coho salmon. The number of respondents in the Statewide Harvest Survey (SWHS) was not sufficient to produce a viable estimate of coho salmon harvested in Nakwasina Sound, including Nakwasina River (Howe et al. 1995, 1996, 2001a-d; Jennings et al. 2004, 2006a-b, 2007, 2009, 2010a-b; Mills 1985-1994; Walker et al. 2003). However, anecdotal information suggests that the harvest in the freshwaters of Nakwasina River is a couple hundred fish annually.

In the 1960s the majority of riparian area in the anadromous portion of Nakwasina River valley was clear-cut to the streambank (Greg Killinger, personal communication, Sitka Ranger District, U.S. Forest Service, Sitka).

Since 1980, annual peak foot survey counts have been conducted on Nakwasina River to provide an indication of abundance, which are collectively examined for trends. Annual peak counts in Nakwasina River represent the largest of 5 systems surveyed annually in the Sitka area. Surveys conducted from 1980 to 2008 have documented 47 (1987) to 996 (2006) adult coho salmon spawners (Table 2).

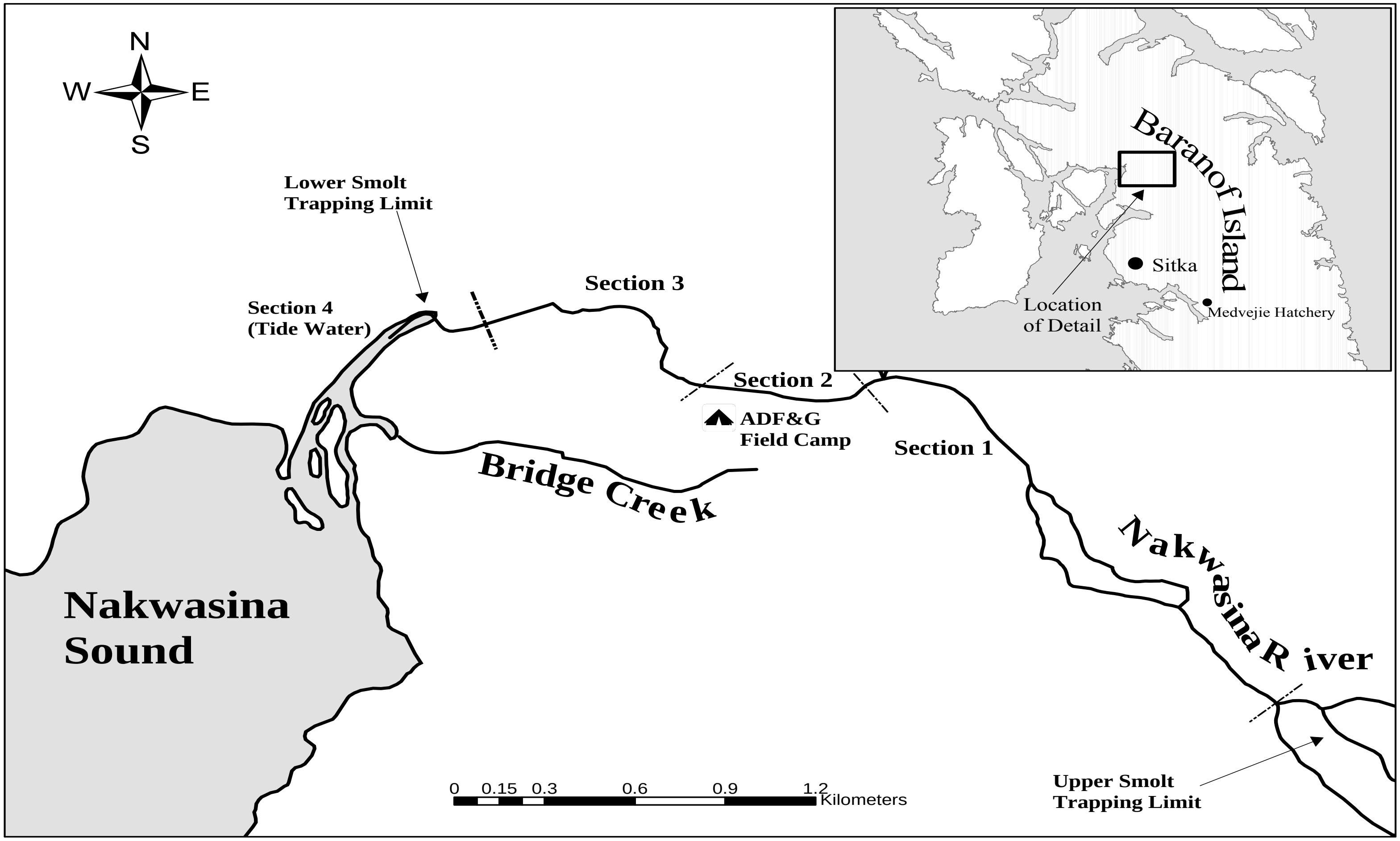

Figure 1.–Map showing Nakwasina River area, including major tributaries and location of ADF&G research sites and stream sections.

Table 2.–Peak escapement counts of coho salmon in the Sitka Area, 1980-2008.

	Sinitsin Creek			St. John Baptist Bay Creek			Starrigavan River			Eagle River			Black River			Nakwasina River		
Year	Survey type	Peak survey date	No. of coho	Survey type	Peak survey date	No. of coho	Survey type	Peak survey date	No. of coho	Survey type	Peak survey date	No. of coho	Survey type	Peak survey date	No. of coho	Survey type	Peak survey date	No. of coho
1980	Foot	30-Sep	39	Foot	9-Oct	26	Foot			Foot	7-Oct	9	Foot	26-Oct	328	Foot	29-Oct	70
1981	Foot	6-Oct	85	Foot	14-Oct	51	Foot	20-Oct	170	Foot	17-Oct	28				Foot	7-Oct	780
1982	Foot	20-Oct	46	Foot			Foot	21-Oct	317									
1983	Foot	27-Sep	31	Foot	13-Oct	20	Foot	6-Oct	45							Foot	14-Oct	217
1984	Foot	10-Oct	160	Foot	10-Oct	154	Foot	10-Oct	385	Foot	16-Oct	7	Helo	3-Oct	425	Foot	17-Oct	715
1985	Foot	15-Oct	144	Foot	8-Oct	109	Foot	11-Oct	193	Foot	9-Sep	61	Helo	7-Oct	1,628	Foot	7-Oct	408
1986	Foot	30-Sep	4	Foot	10-Oct	9	Foot	10-Oct	57	Foot	26-Sep	245	Helo	10-Oct	312	Foot	28-Oct	275
1987	Foot	23-Sep	21	Foot	23-Sep	4	Foot	9-Oct	36	Foot	24-Sep	167	Helo	9-Oct	262	Foot	30-Oct	47
1988	Foot	3-Oct	56	Foot	3-Oct	71	Foot	12-Oct	45	Foot	2-Sep	10	Helo	10-Oct	280	Foot	27-Oct	104
1989	Foot	5-Oct	76	Foot	5-Oct	89	Foot	13-Oct	101	Weir	2-Oct	131	Helo	13-Oct	181	Foot	19-Oct	129
1990	Foot	1-Oct	80	Foot	1-Oct	38	Foot	17-Oct	39	Snorkel	2-Oct	214	Helo	4-Oct	842	Foot	31-Oct	195
1991	Foot	1-Oct	186	Foot	10-Oct	107	Foot	2-Oct	142	Snorkel	17-Oct	454	Helo	17-Oct	690	Foot	25-Oct	621
1992	Foot	23-Sep	265	Foot	14-Oct	110	Foot	12-Oct	241	Snorkel	6-Oct	629	Helo	6-Oct	866	Foot	30-Oct	654
1993	Foot	7-Oct	213	Foot	6-Oct	90	Foot	13-Oct	256	Snorkel	13-Oct	513	Helo	7-Oct	764			
1994	Foot	30-Sep	313	Foot	30-Sep	227	Foot	11-Oct	304	Snorkel	1-Oct	717	Helo	14-Oct	758	Foot	14-Oct	404
1995	Foot	26-Sep	152	Foot	5-Oct	99	Foot	6-Oct	274	Snorkel	5-Oct	336	Helo	27-Sep	1,265	Foot	29-Sep	626
1996	Foot	2-Oct	150	Snorkel	2-Oct	201	Foot	17-Oct	59	Snorkel	30-Sep	488	Helo	30-Sep	385	Foot	30-Oct	553
1997	Foot	29-Sep	90	Snorkel	30-Sep	68	Foot	27-Oct	55	Snorkel	30-Sep	296	Helo	30-Sep	686	Foot	14-Nov	239
1998	Foot	1-Oct	109	Snorkel	9-Oct	57	Foot	8-Oct	123	Snorkel	9-Oct	300	Helo	8-Oct	1,520	Foot	2-Nov	653
1999	Snorkel	11-Oct	48	Snorkel	29-Oct	27	Snorkel	8-Oct	167				Helo	4-Oct	1,590	Snorkel	12-Nov	291
2000	Foot	26-Sep	62	Snorkel	26-Oct	32	Snorkel	8-Oct	144	Snorkel	29-Sep	108	Helo	2-Oct	880	Foot	8-Nov	419
2001	Foot	5-Oct	132	Snorkel	4-Oct	80	Snorkel	8-Oct	133	Snorkel	4-Oct	417	Helo	4-Oct	1,080	Foot	14-Nov	753
2002	Foot	10-Oct	169	Snorkel	2-Oct	100	Foot	10-Oct	227	Snorkel	10-Oct	659	Helo	3-Oct	1,994	Foot	5-Nov	713
2003	Foot	29-Sep	102	Snorkel	30-Sep	91	Foot	2-Oct	95	Snorkel	9-Oct	373	Helo	2-Oct	1,055	Foot	31-Oct	440
2004	Foot	3-Oct	112	Snorkel	1-Oct	80	Foot	2-Oct	143	Snorkel	11-Oct	391	Helo	7-Oct	380	Foot	8-Nov	399
2005	Foot	4-Oct	67	Snorkel	14-Oct	173	Foot	7-Oct	76	Snorkel	14-Oct	460	Helo	6-Oct	106	Foot	7-Nov	892
2006	Foot	1-Oct	152	Snorkel	1-Oct	121	Foot	8-Oct	386	Snorkel	12-Oct	992	Helo	12-Oct	1,100	Foot	6-Nov	996
2007	Foot	4-Oct	39	Snorkel	4-Oct	86	Foot	8-Oct	130	Snorkel	9-Oct	426	Helo	4-Oct	745	Foot	6-Nov	385
2008	Foot	6-Oct	74	Snorkel	6-Oct	128	Foot	9-Oct	96	Snorkel	8-Oct	66	Helo	6-Oct	500	Foot	12-Nov	839
Mean (1980-2007)			110			87			159			327			793			475
5-yr Mean (2004-2008)			89			118			166			467			566			702

METHODS

SMOLT TAGGING AND SAMPLING

From April 11 to May 23, 2006, and April 17 to May 15, 2007 between 50 and 100 G-40 minnow traps were baited with salmon roe and fished daily in Nakwasina River. Traps were fished 24 hours per day, approximately 6 days per week and checked at least once each day. Traps were set along mainstem banks and in backwater areas of the lower river between the estuary and approximately 6 km upstream. Traps were distributed and redistributed opportunistically to maximize catch by targeting areas of likely rearing habitat, unfished areas, and areas known to produce relatively high catch rates. After the first day of trapping each year, captured fish were examined to determine an appropriate minimum tagging length. Generally, most fish were of a uniform length and exhibited a natural size break between young-of-the-year and age-1. fish. Coho salmon smolt ≥70 mm FL in 2006 and ≥65 mm FL in 2007 were removed from minnow traps and transported to holding pens at the campsite each day. Other species (primarily Dolly Varden) and small coho fry (<70 mm FL in 2006 and <65 mm FL in 2007) were counted and released at the capture site.

Every 2-3 days, all live coho salmon smolt were tranquilized with a solution of tricane methane-sulfonate (MS-222)[1] and injected with a CWT. Fish were then marked externally by excising the adipose fin. Tagging and marking followed the methods of Koerner (1977) and Magnus et al. (2006). All tagged fish were held overnight in a net pen to test for mortality, tag retention, and adipose finclip status and released. To test for tag retention, 100 fish were randomly selected and passed through a Northwest Marine Mark IV Portable Sampling Detector™. If tag retention was 98% or greater, all fish were counted, mortalities recorded, and released. If tag retention was 97% or less, all fish were tested for tag retention and those not possessing a tag were retagged. The number of fish tagged, number of tagging-related mortalities, and number of fish that had shed their tags were recorded on *ADF&G Tagging Summary and Release Information Forms* which were submitted to ADF&G Division of Commercial Fisheries Mark, Tag and Age Laboratory (Tag Lab) in Juneau when fieldwork ended.

Three separate tag codes were used to identify different components of the smolt run. Small smolt (≥70 mm in 2006 and ≥65 mm in 2007 but less than 85 mm FL) were tagged with codes 04-11-45 in 2006 and 04-13-07 in 2007, while large smolt (≥85 mm FL) were tagged with codes 04-11-46 and 04-13-08. These tag codes were used to identify potential differential survival based on size at smolting. A third tag code (04-11-47 in 2006 and 04-13-09 in 2007) was used for all fish ≥65 mm or ≥70 mm that were captured in an unnamed tributary to Nakwasina (Figure 1) that is connected only intermittently. This tributary, referred to as “Bridge Creek”, empties into salt water approximately ½ km from the outlet of Nakwasina River, except at high tides when the two appear to be connected by a small freshwater passage. This third tag code was used to determine if fish emigrating from this tributary spawn in the mainstem of Nakwasina River and to examine differential survival by location of capture.

Smolt were measured from snout to fork of tail (FL) to the nearest 1 mm, weighed to the nearest 0.1 g, and sampled for scales. Twelve to 15 scales were removed from the preferred area on the left side of the coho salmon smolt (Scarnecchia 1979). Scales were sandwiched between two 1x 3-in microscope slides and numbered consecutively for each sampled fish. Slides were taped

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1 Product names used in the publication are included for scientific completeness but do not constitute product endorsement.

together and the number and length of each fish was written on the frosted portion of the bottom slide according to scale position on the slide. Ages were determined postseason.

INSTREAM MARK-RECAPTURE SAMPLING, CODED WIRE TAG RECOVERY, AND MARINE HARVEST SAMPLING

During the fall of 2007 and 2008, an open population mark-recapture experiment was used to estimate escapement. This was done in conjunction with CWT recovery efforts that provided information for estimation of smolt abundance with a closed population model.

Sampling occurred during 2- or 3-day periods once each week from September 13 through December 5, 2007 and October 4 through November 26, 2008. Adult coho salmon were captured using a 3.6 x 22.5-m, 3.75-cm mesh beach seine and a 3.0 x 35-m, 7.5-cm mesh tangle net. Hook-and-line gear was also used to supplement net captures. Carcasses were sampled opportunistically when observed.

The stream was divided into 4 sections (Figure 1). Section 1 extended from river kilometer (rkm) 7.75 downstream to rkm 4.1. The portion of the river upstream of rkm 7.75 was not included because few fish have been observed in this section, and the presence of excessive amounts of woody debris and undercut banks were not conducive to capturing fish. Section 2 extended from rkm 4.1 downstream to rkm 3.7, and section 3 extended from rkm 3.7 to rkm 3.4. Section 4 extended from rkm 3.4 to tide water. Sampling was concentrated in sections 2 and 3 because 2 large pools located therein contained the majority of adult coho salmon visible in the river at any given time. These pools enabled effective deployment of the beach seine and tangle net.

All coho captured were examined for presence or absence of their adipose fin (signifying the presence of a CWT). Approximately every other coho missing its adipose fin was sacrificed, head removed, and sent to the Tag Lab for dissection and decoding. All captured coho salmon were also examined for an anchor tag and opercle punch combination. All coho salmon absent this combination were measured to the nearest mm FL, tagged with uniquely numbered Floy™ T-Bar anchor tags, given a secondary mark (opercle punch) to permit estimation of tag loss, examined to determine sex and condition, and sampled to collect scales for aging. Tags were inserted 1 cm below the insertion of the dorsal fin on the left side of the fish. Secondary marks were varied weekly to allow for reconstruction of capture histories in the event Floy™ tags were lost between sampling events. Secondary marks included various combinations of opercle punches that consisted of 0.6 cm diameter holes. The condition of each fish was determined from external characteristics using the following convention:

1)	Bright	Ocean bright or nearly ocean bright;
2)	Blush	Some color (primarily blush red);
3)	Dark	Dark color (primarily red);
4)	LPS (live post-spawner)	Spawned out but not yet dead;
5)	Carcass	Dead spawned fish; and,
6)	Mortality	Dead unspawned fish.

For fish captured with a Floy™ tag, the section, gear used, tag number, and condition were recorded and the fish was released. If an opercle punch but no anchor tag was present, the fish was recorded as a valid tag recovery (indicating the tag was shed), retagged, and examined for condition.

All carcasses that could be retrieved were also inspected for marks, recorded, and heads were removed if the adipose fin was missing. Carcasses were slashed on the left side along the midline to prevent resampling.

Sex was determined from external characteristics. Scale samples, consisting of 4 scales from the preferred area near the lateral line on an imaginary line from the insertion of the posterior dorsal fin to the anterior origin of the anal fin (Scarnecchia 1979), were collected and affixed to a gum card in the field. Postseason, scale images were impressed on acetate and ages were determined by examining the impressions under a microscope. Criteria used to assign ages were similar to those of Moser (1968).

Harvest of coho salmon originating from Nakwasina River was estimated from fish sampled in both commercial and marine sport fisheries. Fisheries personnel with the ADF&G Division of Commercial Fisheries port-sampling program examined commercially caught fish at processing locations and recovered coho with missing adipose fins[2]. Similarly, the Division of Sport Fish employed a creel survey program to examine fish caught in the sport fishery (e.g., see Hubartt et al. 2002). When possible, heads of fish without an adipose fin were removed and sent to the Tag Lab for tag detection and decoding. Because multiple fisheries exploited coho salmon over several months, harvest was estimated over several strata, each a combination of time, area, and type of fishery. Statistics from the commercial troll fishery were stratified by fishing period and by fishing quadrant. Statistics from the marine sport fishery were stratified bi-weekly.

FOOT SURVEY COUNTS

Adult coho salmon in Nakwasina River were counted visually approximately every other week during October and November each year. Visual counts were conducted by 2 experienced observers either during or 1 day after instream sampling efforts. Only fish positively identified as coho salmon were counted. Counts were conducted between the uppermost portion of the survey area (rkm 7.75) and a pool near the high tide mark at rkm 0.25. Uncontrolled variables included observer abilities, weather conditions, and water clarity. Weather conditions, water clarity, and counts were recorded by stream section.

Bridge Creek was examined opportunistically during the course of sampling to determine if coho salmon used it for spawning or rearing. To date, no coho spawning activity has been observed in Bridge Creek.

ESTIMATE OF SMOLT ABUNDANCE AND SIZE

Chapman's modification of the Petersen estimator (Seber 1982) was used to estimate smolt abundance. Several conditions must be met for unbiased estimates:

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[2] For marking protocol, see Oliver, G. *Unpublished.* Alaska Department of Fish and Game coded wire tag sampling program, detailed sampling instructions, commercial fisheries sampling. Available through Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau.

1. there is no recruitment or immigration to the population–only fish that were present in the population during the smolt marking are present in the population of fish inspected for marks as adults;
2. there is no tagging induced behavior or mortality–tagged fish behave the same as untagged fish after the marking event;
3. fish do not lose their marks and all marks are recognizable;
4. tag codes and release locations can be correctly determined for all adult fish observed with missing adipose fins; and
5. all fish marked as juveniles are smolt.

In addition, at least 1 set of conditions on mortality and sampling must be met. Because significant mortality occurs between sampling events, these conditions must be evaluated and satisfied concurrently. At least 1 of the following sets of conditions must be met:

S1. all fish have an equal probability of being captured and marked during the first event; or

S2. all fish have the same probability of surviving between events whether marked or unmarked and across all tagging groups <u>and</u> complete mixing of marked and unmarked fish occurs prior to the second event; or

S3. all fish have the same probability of surviving between events whether marked or unmarked and across all tagging groups <u>and</u> all fish have an equal probability of being captured and inspected for marks during the second event.

When possible, these conditions were evaluated using experimental data, and in some cases by indirect knowledge. Otherwise, they were ensured by exercising control over experimental procedures. Equal survival between tagging groups was evaluated using contingency table analysis to test for lack of independence between tagging group and probability of recovery during adult sampling. Contingency table analysis was also used to test for lack of independence between sampling events and freshwater age.

Estimates of mean smolt length and weight-at-age and their variances were calculated with standard sample summary statistics (Cochran 1977).

ESTIMATE OF HARVEST

The contribution (r_{ij}) of release group j to a fishery stratum i was estimated as:

$$\hat{r}_{ij} = N_i\left[\frac{m_{ij}}{\lambda_i n_i}\right]\theta_j^{-1}; \qquad \lambda_i = \frac{a_i' t_i'}{a_i t_i} \tag{1}$$

where:

N_i = total harvest in fishery stratum i,
n_i = number of fish inspected in fishery stratum i (the sample),
a_i = number of fish which were missing an adipose fin,
a_i' = number of heads that arrived at the lab,
t_i = number of heads with CWTs detected,
t_i' = number of CWTs that were dissected from heads and decoded,
m_i = number of CWTs with code(s) of interest, and
θ_j = fraction of the cohort tagged with code(s) of interest.

When N_i and θ_j are known without error, an unbiased estimate of the variance of $\hat{r}_{ij}$ can be calculated as shown by Clark and Bernard (1987). However, N_i is estimated with error in sport fisheries, and θ_j is estimated with error on Nakwasina River because wild stocks are tagged. Because of these circumstances, estimates of the variance of $\hat{r}_{ij}$ based on large sample approximations were obtained using the appropriate equations in Bernard and Clark (1996).

The total harvest for a cohort was calculated as the sum of strata estimates:

$$\hat{H} = \sum_i \sum_j \hat{r}_{ij} \tag{2}$$

$$Var\left[\hat{H}\right] = \sum_i \sum_j v\left[\hat{r}_{ij}\right] \tag{3}$$

SPAWNING ESCAPEMENT

2007

The escapement in 2007 of adult (age-.1) coho salmon in Nakwasina River was estimated with a Jolly-Seber (JS) experiment (Seber 1982) using the model described by Schwarz et al. (1993). Subadult (age-.0) coho salmon were much smaller than adults and were ignored. Weekly sampling trips spanning the time of immigration were conducted to mark and recapture adults. Following the work of Sykes and Botsford (1986), repeated recaptures of carcasses "captured" in a decayed condition were not included. Carcasses were slashed on the left side along the midline to prevent resampling.

In general, escapement (E) is the total number of immigrants (B_i) between the first and last sampling occasion, including fish that enter the system and die between any 2 sampling occasions (i), and fish that enter before the first sampling occasion (B_0) and after the last sampling occasion (B_s): $\hat{E} = \hat{B}_0 + ... + \hat{B}_{s-2} + \hat{B}_{s-1} + B_s$. Because sampling began early in immigration and continued until it was virtually over, $B_0 + B_1$ was estimated from an estimate of abundance just before the second JS sampling event ($\hat{N}_2$), and ignored immigration B_{s+1} and beyond as suggested by Schwarz et al (1993). The resulting (albeit negatively biased) estimator is thus:

$$\hat{E} = \hat{N}_2\left(\frac{log\,\hat{\phi}_1}{\hat{\phi}_1 - 1}\right) + \hat{B}_2\left(\frac{log\,\hat{\phi}_2}{\hat{\phi}_2 - 1}\right) + ... + \hat{B}_{s-2}\left(\frac{log\,\hat{\phi}_{s-2}}{\hat{\phi}_{s-2} - 1}\right) \tag{4}$$

where $\hat{B}_i$ are JS estimates of the number of fish present at sample time $i+1$ that immigrated between i and $i+1$, $\hat{\phi}_i$ is the survival rate from i to $i+1$, and the factors $\frac{\log(\phi_i)}{\phi_i - 1}$ account for fish that enter and die between samples under the assumption that natural mortality is uniformly distributed between sampling events. The computer program POPAN (Arnason and Schwarz 1995) was used to estimate the JS parameters, and out-of-bounds estimates were constrained to admissible values (Schwarz and Arnason 1996; Schwarz et al. 1993). Variance of escapement was estimated using the delta method and the asymptotic variance and covariances in Schwarz et al. (1993), and expected values of the sampling statistics from POPAN.

Assumptions of the standard (full) JS model (Seber 1982) include:

1. every fish in the population has the same probability of capture in the i^{th} sample;
2. every marked fish has the same probability of surviving from the i^{th} to the $(i+1)^{th}$ sample and being in the population at the time of the $(i+1)^{th}$ sample;
3. every fish caught in the i^{th} sample has the same probability of being returned to the population;
4. marked fish do not lose their marks between sampling events and all marks are reported on recovery; and
5. all samples are instantaneous (sampling time is negligible).

Chi-square goodness-of-fit tests were used to test for homogenous capture and survival probabilities by tagged status (Pollock et al. 1990). The first test is equivalent to the Robson (1969) test for short-term mortality. The second test is reported to be better at detecting heterogeneous survival probabilities (Pollock et al. 1990). The sum of the chi-squares from each test is an overall test statistic for violations of the first 3 assumptions above (equal probability of capture, survival, and return to the population).

The equal probability of capture assumption can also be violated if sampling is size or sex selective. Although differences in the size of adult coho salmon are small, a hypothesis that fish of different sizes were captured with equal probabilities was tested by using Kolmogorov-Smirnov (K-S) 2-sample tests (Conover 1980). Sex-selective sampling was investigated using contingency table analysis with a χ^2 test statistic (Cochran 1977) comparing the number of males and females marked with those recaptured.

Assumptions 3, 4, and 5 were thought to be robust in this experiment. With regard to assumption 3, the only fish that are not returned to the experiment during sampling are those with missing adipose fin, indicating the presence of a CWT. There is no reason to believe the presence or absence of a CWT imbedded deep in cartilage has any effect on adult inriver survival, spawning activity, or the probability that a fish is captured during inriver sampling. With regard to assumption 4, the combination of opercle punch and anchor tag marks and diligent inspection of all fish sampled has been sufficient to ensure that an accurate capture history is recorded for each fish sampled. With regard to assumption 5, the ability to observe multiple recaptures over the course of the experiment indicates that fish persist in the sampling sections across several sampling events, so while sampling events occupy 2-3 days per week, the potential for bias due to sampling not being "instantaneous" is negligible.

2008

Spawning escapement in 2008 was estimated through the use of an expansion factor derived by comparing open population estimate models to peak foot counts between 2000 and 2007. The expansion factor used for 2008 was 4.3.

AGE AND SEX COMPOSITION

The proportion of the spawning population composed of a given age or sex was estimated as (Cochran 1977):

$$\hat{p}_j = \frac{n_j}{n} \tag{5}$$

$$Var(\hat{p}_j) = \frac{\hat{p}_j(1-\hat{p}_j)}{n-1} \tag{6}$$

where:

p_j = the proportion in the population in group j;

n_j = the number in the sample of group j; and

n = sample size.

To reduce bias due to inseason changes in age composition, samples were obtained systematically.

ESTIMATES OF TOTAL RUN, EXPLOITATION, AND MARINE SURVIVAL

Estimates of total run (i.e., harvest and escapement) for coho salmon returning to Nakwasina River in 2007 and 2008 and the associated exploitation rate in commercial and sport fisheries were based on the sum of the estimated harvest and escapement:

$$\hat{N}_R = \hat{H} + \hat{E}\ . \tag{7}$$

The variance of the estimated run was calculated as the sum of the variances for estimated escapement and harvest:

$$Var[\hat{N}_R] = Var[\hat{H}] + Var[\hat{E}]. \tag{8}$$

The estimate of exploitation rate and variance were calculated using (Mood et al. 1974):

$$\hat{U} = \frac{\hat{H}}{\hat{N}_R} \tag{9}$$

$$Var\left[\hat{U}\right] \approx \frac{Var[\hat{H}]\,\hat{E}^2}{\hat{N}_R^4} + \frac{Var[\hat{E}]\,\hat{H}^2}{\hat{N}_R^4}\ . \tag{10}$$

The estimated survival rate of smolt to adults and variance were calculated using (Mood et al. 1974):

$$\hat{S} = \frac{\hat{N}_R}{\hat{N}_s} \tag{11}$$

$$Var\,[\hat{S}\,] \approx \hat{S}^{\,2}\left[\frac{Var\,[\hat{N}_R\,]}{\hat{N}_R^{\,2}} + \frac{Var\,[\hat{N}_s\,]}{\hat{N}_s^{\,2}}\right]. \tag{12}$$

RESULTS

SMOLT TAGGING, SAMPLING, AND ABUNDANCE

2006

Smolt abundance in 2006 was estimated to be 37,785 (SE = 2,579). Between April 11 to May 23, 2006, 10,661 coho smolt from Nakwasina River and its tributaries were captured and coded-wire-tagged. Tag retention was 100.0% for size-small smolt (70-84 mm), 99.8% for size-large smolt (≥85 mm) and 99.7% for smolt ≥70 mm captured in Bridge Creek. In addition, a total of 6 overnight mortalities occurred. Adjusting for tag retention and mortalities, the total number of valid tag releases was calculated as 10,644. Of these, 5,289 (49.7%) were small smolt captured in the mainstem of Nakwasina River, while 2,442 (22.9%) were large smolt (Table 3). The remaining 2,913 (27.4%), were fish ≥70 mm captured in Bridge Creek.

Table 3.–Numbers and χ^2 tests for independence for smolt and adult coho salmon from the Nakwasina River and Bridge Creek, 2000-2008.

Year	≥70 mm[a]	≥85 mm	Bridge Creek	Total	≥70 mm[a]	≥85 mm	Bridge Creek
Spring smolt releases					Percentage of total		
2000	5,446	1,831	3,042	10,319	53%	18%	29%
2001	6,979	1,434	1,986	10,399	67%	14%	19%
2002	3,566	874	1,246	5,686	63%	15%	22%
2003	9,925	2,533	3,304	15,762	63%	16%	21%
2004	5,165	2,692	1,914	9,771	53%	28%	20%
2005	7,158	2,083	3,748	12,989	55%	16%	29%
2006	5,289	2,442	2,913	10,644	50%	23%	27%
2007	7,591	1,071	1,971	10,633	71%	10%	19%
Adult escapement recoveries							
2001	75	35	40	150	50%	23%	27%
2002	146	39	15	200	73%	20%	8%
2003	145	28	24	197	74%	14%	12%
2004	180	77	44	301	60%	26%	15%
2005	87	48	37	172	51%	28%	22%
2006	100	21	44	165	61%	13%	27%
2007	33	15	24	72	46%	21%	33%
2008	70	10	10	90	78%	11%	11%
Adult fisheries recoveries							
2001	48	22	29	99	48%	22%	29%
2002	27	22	5	54	50%	41%	9%
2003	28	8	14	50	56%	16%	28%
2004	52	22	24	98	53%	22%	24%
2005	45	15	20	80	60%	26%	15%
2006	28	16	37	81	35%	20%	46%
2007	25	20	27	72	35%	28%	38%
2008	50	12	5	67	75%	18%	7%
All adults combined							
2001	123	57	69	249	49%	23%	28%
2002	173	61	20	254	68%	24%	8%
2003	173	36	38	247	70%	15%	15%
2004	232	99	68	399	58%	25%	17%
2005	132	63	57	252	60%	26%	15%
2006	128	37	81	246	52%	15%	33%
2007	58	35	51	144	40%	24%	35%
2008	120	22	15	157	76%	14%	10%

Component 1	Component 2	$\chi 2$	p
Nakwasina smolt 2000	All adults 2001	4.63	0.099
Nakwasina smolt 2000	Adult escapement 2001	3.11	0.191
Adult fisheries 2001	Adult escapement 2001	0.21	0.901
Smolt 2001	All adults 2002	36.95	0.000
Smolt 2001	Adult escapement 2002	20.24	0.000
Adult fisheries 2002	Adult escapement 2002	11.46	0.003
Smolt 2002	All adults 2003	7.34	0.026
Smolt 2002	Adult escapement 2003	12.85	0.002
Adult fisheries 2003	Adult escapement 2003	8.34	0.016
Nakwasina smolt 2002	Nakwasina adults 2003	0.84	0.360
Nakwasina smolt 2002	Nakwasina escapement 2003	1.39	0.238
Nakwasina fisheries 2003	Nakwasina escapement 2003	0.76	0.383
Adult fisheries 2004	Adult escapement 2004	5.10	0.078
Nakwasina smolt 2003	Nakwasina adults 2004	23.98	0.000
Nakwasina smolt 2003	Nakwasina escapement 2004	23.65	0.000
Nakwasina smolt 2003	Bridge Creek smolt 2003	3.62	0.057
Nakwasina small smolt 2003	Nakwasina large smolt 2003	18.09	0.000
Nakwasina fisheries 2004	Nakwasina escapement 2004	5.10	0.078
Nakwasina smolt 2004	Nakwasina adults 2005	1.84	0.400
Nakwasina smolt 2004	Nakwasina escapement 2005	0.51	0.775
Nakwasina smolt 2004	Bridge Creek smolt 2004	1.51	0.219
Nakwasina small smolt 2004	Nakwasina large smolt 2004	0.34	0.560
Nakwasina fisheries 2005	Nakwasina escapement 2005	2.15	0.342
Nakwasina smolt 2005	Nakwasina adults 2006	2.03	0.363
Nakwasina smolt 2005	Nakwasina escapement 2006	2.34	0.311
Nakwasina smolt 2005	Bridge Creek smolt 2005	2.03	0.155
Nakwasina small smolt 2005	Nakwasina large smolt 2005	1.89	0.169
Nakwasina fisheries 2006	Nakwasina escapement 2006	13.17	0.001
Nakwasina smolt 2006	Nakwasina adults 2007	6.17	0.046
Nakwasina smolt 2006	Nakwasina escapement 2007	1.30	0.522
Nakwasina smolt 2006	Bridge Creek smolt 2006	4.76	0.029
Nakwasina small smolt 2006	Nakwasina large smolt 2006	1.59	0.207
Nakwasina fisheries 2007	Nakwasina escapement 2007	1.99	0.369
Nakwasina smolt 2007	Nakwasina adults 2008	9.96	0.007
Nakwasina smolt 2007	Nakwasina escapement 2008	3.32	0.191
Nakwasina smolt 2007	Bridge Creek smolt 2007	8.51	0.004
Nakwasina small smolt 2007	Nakwasina large smolt 2007	1.30	0.254
Nakwasina fisheries 2008	Nakwasina escapement 2008	1.85	0.396

[a] In 2003 and 2007 smolt ≥65 mm were tagged.

Smolt captured in the mainstem of Nakwasina River that were age 1. (those rearing for 1 year in fresh water) comprised 99.6% of sampled smolt and averaged 81 mm FL (SE = 0.45) and 5.3 g (SE = 0.10, Table 4). Only 1 age-2. coho smolt was captured in the mainstem and it measured 113 mm FL and 13.7 g. The combined catch averaged 82 mm FL (SE = 0.45) and 5.4 g (SE = 0.11). Average length and weight of captured coho remained approximately the same throughout the tagging effort. Age-1. fish from Bridge Creek comprised 100% of sampled smolt and averaged 85 mm FL (SE = 0.85) and 6.0 g (SE = 0.20, Table 4).

Table 4.–Estimated fork length, weight, and age of coho salmon smolt from Nakwasina River and Bridge Creek in 2006 and 2007.

	Nakwasina						Bridge Creek			
	Age-1.		Age-2.		Combined		Age-1.		Age-2.	
Statistic	Length	Weight	Length	Weight	Length	Weight	Length	Weight	Length	Weight
					2006[b]					
Average[a]	81	5.3	113	13.7	82	5.4	85	6.0	-	-
Standard error	0.45	0.10	-	-	0.45	0.11	0.85	0.20	-	-
Sample size	295	255	1	1	305	263	108	100	-	-
					2007[b]					
Average[a]	76	4.5	109	13	76	4.6	78	4.6	-	-
Standard error	0.46	0.09	-	-	0.48	0.10	1.0	0.19	-	-
Sample size	336	336	1	1	342	342	70	70	-	-

[a] Length measured to the nearest millimeter and weight to the nearest 0.1 gram.

[b] Minimum tagging size in 2006 was 70mm FL and 65mm FL in 2007

The proportions of smolt tagged in 2006 with each of 3 tag codes were significantly different than that observed in the spawning escapement in 2007 ($\chi^2 = 6.17$, P = 0.046, Table 3). Smolt emigrating from Bridge Creek in 2006 appeared to survive at a slightly higher rate compared to the Nakwasina smolt when both large and small size categories were combined ($\chi^2 = 4.76$, P = 0.029, Table 3). The tag groups of large and small Nakwasina River smolt had similar survival based on rates of recovery of tagged adult fish ($\chi^2 = 1.59$, P = 0.207, Table 3).

2007

Smolt abundance in 2007 was estimated to be 59,457 (SE = 4,975). Between April 17 and May 15, 2007, 10,633 coho smolt from Nakwasina River and its tributaries were captured and coded-wire-tagged. Tag retention was 100% and there were no overnight mortalities. This left 10,633 valid tag releases. Of these, 7,591 (71.4%) were small smolt captured in the mainstem of Nakwasina River, while 1,071 (10.1%) were large smolt (Table 3). Nineteen percent (19%), or 1,971 were fish ≥65 mm captured in Bridge Creek.

Smolt captured in the mainstem of Nakwasina River that were age-1. fish comprised 99.7% of sampled smolt and averaged 76 mm FL (SE = 0.46) and 4.5 g (SE = 0.09, Table 4). One age-2. coho smolt was captured from mainstem Nakwasina and was measured as 109 mm FL and 13 g. The combined catch averaged 76 mm FL (SE = 0.48) and 4.6 g (SE = 0.10). Average length and weight of captured coho remained approximately the same throughout the tagging effort. Age-1. fish from Bridge Creek comprised 100% of sampled smolt and averaged 78 mm FL (SE = 1.0) and 4.6 g (SE = 0.19, Table 4).

The proportions of smolt tagged in 2007 with each of 3 tag codes were significantly different than that observed in the spawning escapement in 2008 ($\chi^2 = 9.96$, P = 0.007, Table 3). Smolt emigrating from Bridge Creek in 2007 appeared to survive at a slightly lower rate compared to the Nakwasina smolt when both large and small size categories were combined ($\chi^2 = 8.51$, P = 0.004, Table 3). The tag groups of large and small Nakwasina River smolt had similar survival based on rates of recovery of tagged adult fish ($\chi^2 = 1.30$, P = 0.254, Table 3).

INSTREAM CODED WIRE TAG RECOVERY AND AGE-SEX COMPOSITION

2007

The CWT fraction of adult coho salmon sampled in Nakwasina River during 2007 was 0.234. Of the 535 adult coho salmon examined, 125 had an adipose finclip.

The proportion of freshwater age-1. fish in the 2007 sample was 97% (Table 5, Appendix A1). Additionally, no differences were detected in freshwater age by sex ($\chi^2 = 0.70$, P = 0.403).

Table 5.–Number of age-1. and age-2. coho salmon smolt and adults, 2007-2008.

	Sample year	2007				
	Brood year	2005	2004	2004	2003	Total aged
	Age class	1.0	2.0	1.1	2.1	
Females	Sample size	-	-	181	4	185
	Percent	-	-	97.8%	2.2%	
	SE	-	-	1.1%	1.1%	
	Mean length	-	-	630	663	
	SE	-	-	2.9	10.9	
Males	Sample size	5	-	180	2	187
	Percent	2.7%	-	96.3%	1.1%	
	SE	0.8%	-	0.8%	0.8%	
	Mean length	326	-	605	648	
	SE	8.0	-	4.4	27.5	
All fish	Sample size	5	-	361	6	372
	Percent	1.3%	-	97.0%	1.61%	
	SE		-	0.7%	0.7%	
	Mean length	326	-	618	658	
	SE	8.0	-	2.7	10.4	

	Freshwater age[a] 1	2	χ2	*P*-value
Adults 2007	366	6	4.08	0.043
Smolt 2006	406	1		
2007 adult males	185	2	0.70	0.403
2007 adult females	181	4		

	Sample year	2008				
	Brood year	2006	2005	2005	2004	Total aged
	Age class	1.0	2.0	1.1	2.1	
Females	Sample size	-	-	211	3	214
	Percent	-	-	98.6%	1.4%	
	SE	-	-	0.8%	0.8%	
	Mean length	-	-	672	662	
	SE	-	-	2.3	11.7	
Males	Sample size	-	-	259	-	259
	Percent	-	-	100.0%	-	
	SE	-	-	0.0%	-	
	Mean length	-	-	659	-	
	SE	-	-	3.8	-	
All fish	Sample size	-	-	470	3	473
	Percent	-	-	99.4%	0.63%	
	SE	-	-	0.4%	0.4%	
	Mean length	-	-	666	662	
	SE	-	-	2.4	11.7	

	Freshwater age[a] 1	2	χ2	*P*-value
Adults 2008	470	3	2.15	0.143
Smolt 2007	337	0		
2008 adult males	259	0	3.65	0.056
2008 adult females	211	3		

[a] Differences between χ2 observations and age class sample sizes are due to unreadable freshwater or saltwater ages.

2008

The CWT fraction of adult coho salmon sampled in Nakwasina River during 2008 was 0.178. Of the 642 adult coho salmon examined, 114 had an adipose finclip.

The proportion of freshwater age-1. fish in the 2008 sample was 99% (Table 5, Appendix A1). Only 3 of 211 females were age 2.1 and all males sampled (n = 259) were aged 1.1. Additionally, freshwater ages by sex were marginally similar ($\chi^2 = 3.65$, P = 0.056).

CONTRIBUTION TO MARINE FISHERIES

2007

The estimated harvest of Nakwasina River coho salmon in sampled marine fisheries in 2007 was 1,013 (SE = 131, Table 6, Figure 2). Nakwasina coho contributed less than 1% of the combined sport, troll, and seine harvest (1,028,238, Table 6) for the areas in which Nakwasina River fish were recovered. The estimated total contribution to the marine sport fishery by Nakwasina coho was 66 fish. Seven percent of Nakwasina coho salmon harvested were caught in the sport fishery, however, relative contributions were higher in sport fisheries (0.21% of the harvest) than troll (0.09% of the harvest). Estimates of freshwater harvest of coho salmon in Nakwasina River based on the Statewide Harvest Survey are not considered reliable because of a low response rate. Anecdotal information suggests that in 2007 a few hundred fish were harvested in the freshwater of Nakwasina River.

Table 6.–Estimated harvest of adult Nakwasina River coho salmon in sport and commercial fisheries sampled in 2007 and 2008.

2007											
TROLL FISHERY											
Period	Dates	Quadrant	Estimated harvest	Inspected	a	a’	t	t’	m	r	SE[r]
3	7/1-8/11	NW	430,115	124,307	1,943	1,864	1,403	1,400	15	199	51
4	8/12-10/6	NW	512,517	122,908	2,800	2,700	2,110	2,107	44	698	112
4	8/12-10/6	NE	44,753	11,111	234	229	161	161	1	15	15
		Subtotal troll fishery	987,385	258,326	4,977	4,793	3,674	3,668	60	912	124
PURSE SEINE FISHERY											
Week	Dates	Quadrant	Estimated harvest	Inspected	a	a’	t	t’	m	r	SE[r]
29	7/15-7/21	SW	3,414	1475	21	21	13	13	1	8	8
32	8/5-8/11	NW	6,011	852	11	11	10	10	1	26	25
		Subtotal seine fishery	9,425	2,327	32	32	23	23	2	34	27
SPORT FISHERY											
Bi-week	Dates	Area	Estimated harvest	Inspected	a	a’	t	t’	m	r	SE[r]
15	7/16-7/29	Sitka	8,961	4666	93	92	77	77	2	14	9
17	8/13-8/26	Sitka	16,315	4293	58	57	43	43	2	28	19
18	8/27-9/9	Sitka	6,152	961	15	15	14	14	1	23	23
		Subtotal sport fishery	31,428	9,920	166	164	134	134	5	66	31
		Total all fisheries	1,028,238	270,573	5,175	4,989	3,831	3,825	67	1,013	131
2008											
TROLL FISHERY											
Period	Dates	Quadrant	Estimated harvest	Inspected	a	a’	t	t’	m	r	SE[r]
4	8/10-10/4	NW	386,748	103,574	2,019	1,988	1,706	1,702	39	844	150
3	6/29-8/9	NW	467,970	137,246	1,812	1,777	1,365	1,357	14	279	76
3	6/29-8/9	NE	35,031	9,585	75	72	48	48	1	22	21
		Subtotal troll fishery	889,749	250,405	3,906	3,837	3,119	3,107	54	1,144	169
PURSE SEINE FISHERY											
Week	Dates	Quadrant	Estimated harvest	Inspected	a	a’	t	t’	m	r	SE[r]
33	8/10-8/16	NW	2,504	733	20	20	19	19	1	19	19
34	8/17-8/23	NW	745	347	19	19	18	18	1	12	12
		Subtotal seine fishery	3,249	1,080	39	39	37	37	2	32	22
SPORT FISHERY											
Bi-week	Dates	Area	Estimated harvest	Inspected	a	a’	t	t’	m	r	SE[r]
16	8/4-8/17	Sitka	6,586	2,228	31	30	28	28	2	35	24
17	8/18-8/31	Sitka	7,629	2,383	31	31	28	28	2	36	25
		Subtotal sport fishery	14,215	4,611	62	61	56	56	4	71	49
Total all fisheries			907,213	256,096	4,007	3,937	3,212	3,200	60	1,247	174

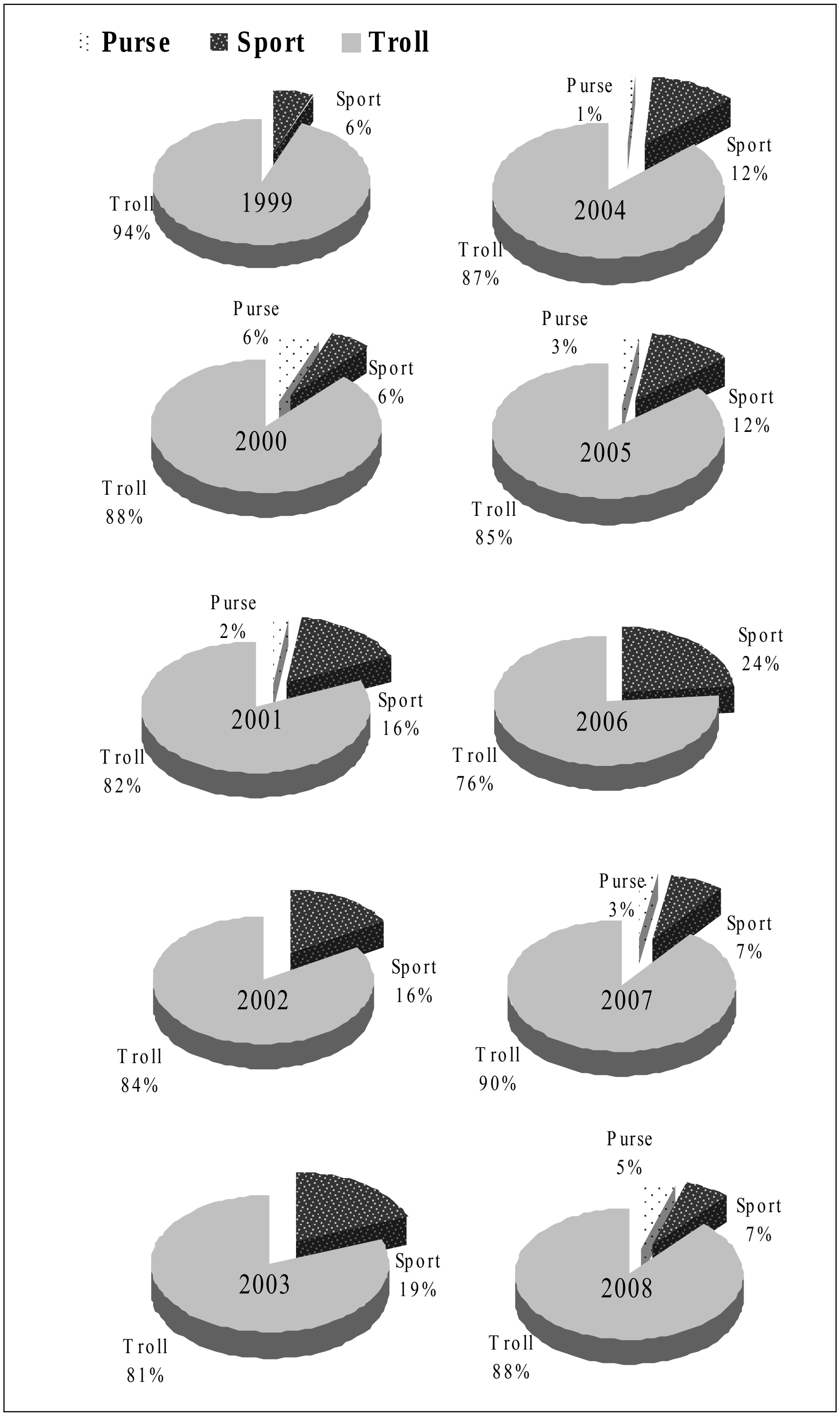

Figure 2.–Portion of Nakwasina coho harvest by fishery between 1999 and 2008 (select recoveries omitted).

In 2007, 69 CWTs from Nakwasina River and Bridge Creek were randomly recovered from 270,573 coho salmon sampled in commercial and sport fisheries, and 3 additional CWTs were recovered incidentally (Appendix A2). Sixty-two coho salmon bearing CWTs with a Nakwasina River code were recovered randomly from Southeast Alaska's commercial troll fisheries, but 2 of these recoveries lacked associated quadrant data. Of the 60 random troll fishery recoveries with quadrant information, 44 were caught in the Northwest Quadrant (Figure 3) between August 12 and October 6, 2007. Five coho salmon bearing CWTs with a Nakwasina River code were recovered in the Sitka sport fishery between July 16 and September 9. Two fish were randomly recovered in the commercial seine fishery.

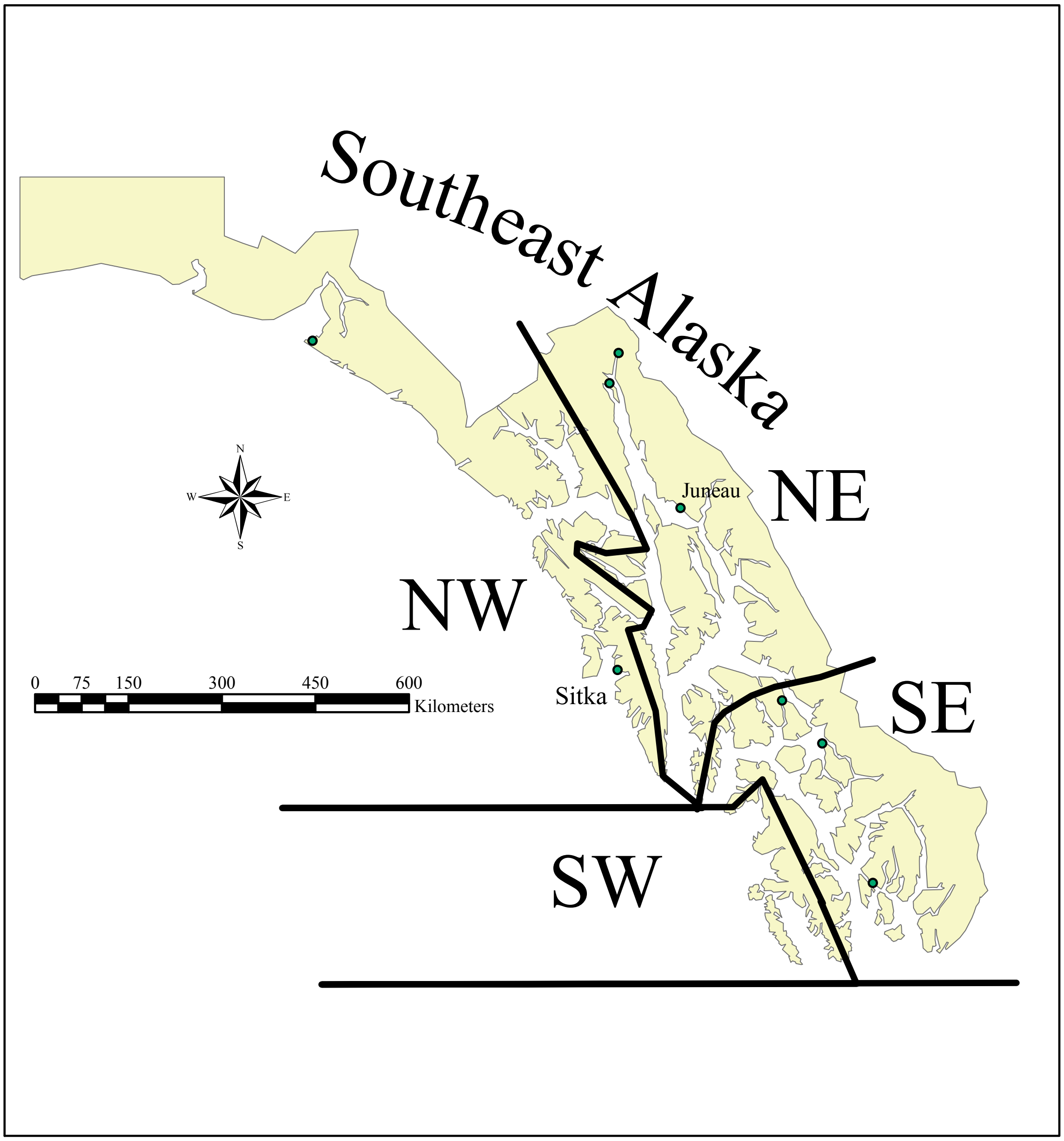

Figure 3.–Map of Southeast Alaska showing the boundaries for CWT quadrants.

Coho salmon bearing CWTs with a Nakwasina River code recovered in the commercial and sport fisheries averaged 564 mm FL (SE = 6.75).

2008

The estimated harvest of Nakwasina River coho salmon in sampled marine fisheries in 2008 was 1,247 (SE = 174, Table 6). In 2008, 60 CWTs from Nakwasina River and Bridge Creek were randomly recovered from 256,096 coho salmon sampled in commercial and sport fisheries and 7 additional CWTs were recovered incidentally (Appendix A2). Fifty-four coho salmon bearing CWTs with a Nakwasina River code were recovered randomly from Southeast Alaska's commercial troll fisheries. Of these, thirty-nine were caught in the Northwest Quadrant (Figure 3) between August 10 and October 4, 2008. Four coho salmon bearing CWTs with a Nakwasina River code were recovered in the Sitka sport fishery between August 4 and August 31, 2008. Three coho salmon bearing CWTs with a Nakwasina River code were recovered in the commercial seine fishery. One of these recoveries was received without associated quadrant information. The remaining 2 recoveries occurred in the Northwest Quadrant. The additional 7 incidentally recovered fish and the 1 fish without quadrant information were not used to estimate harvest.

Nakwasina coho contributed less than 1% of the combined sport, troll, and seine harvest (907,213; Table 6) for the areas in which Nakwasina River fish were recovered. The estimated total contribution to the marine sport fishery by Nakwasina coho was 71 fish. Sport-caught Nakwasina coho salmon comprised 7% of the harvest of that stock in the sampled marine fisheries (Figure 2), but relative contributions were higher for the sport harvest (0.5%) than the troll harvest (0.13%). Estimates of freshwater harvest of coho salmon in Nakwasina River based on the Statewide Harvest Survey are not considered reliable because of a low response rate. Anecdotal information suggests that in 2008 a few hundred fish were harvested in the freshwater of Nakwasina River.

Coho salmon bearing CWTs with a Nakwasina River code recovered in the commercial and sport fisheries averaged 628 mm FL (SE = 6.09).

ESTIMATED SPAWNING ESCAPEMENT, TOTAL RUN, AND MARINE SURVIVAL

2007

The estimated spawning escapement of coho salmon in Nakwasina River in 2007 was 1,000 fish (SE = 222). Altogether, sampling resulted in 958 fish captures – 535 unique adults were captured and examined and 410 recaptures were made (Table 7; Appendix A3). One recaptured fish lost a numbered tag as evidenced by the operculum punches. A total of 81 fish were either sacrificed for their CWTs, or died on capture. Most adult coho captured in Nakwasina River in 2007 were captured with either the beach seine or tangle net, while 21 were captured with hook-and-line (Table 8). Hook-and-line gear was moderately effective at capturing fish, but only when water conditions allowed for sighting fish.

Instream abundance peaked at 451 adults in period 2 (October 14 – 20) and declined to 133 fish in period 8 (December 2 – 8; Table 9). Period-to-period survival rates varied from 0.52 to 1.0 (constrained; Table 9). One estimate of survival was constrained to yield admissible (realistic) values during the estimation procedure.

Table 7.–Summarized mark-recapture data for Nakwasina River coho salmon, 2007 and 2008. Notation follows that in Seber (1982).

Week	Number captured	Number marked caught in m_i	Losses on capture	Subsequently recaptured
		2007		
37	1		1	
40	4		1	
41	34		11	25
42	49	3	7	22
43	112	13	19	95
45	161	38	20	150
46	2	2	1	
47	123	103	16	99
48	37	132	3	19
49	12	119	2	
Grand total	535	410	81	410
		2008		
40	9		9	
44	119		31	36
45	187	15	41	49
46	81	6	5	25
47	199	77	14	10
48	47	22	4	
Grand total	642	120	104	120

Table 8.–Differences in sex composition between capture type, gear, and section, 2007 and 2008.

		2007			
	Females	Males	% Males	$\chi 2$	*P*-value
		Capture			
Captured	272	263	49.16%		
Recapture	195	215	52.44%	1.00	0.318
		Gear Type			
Hook-and-line	13	8	38.10%	1.34	0.247
Seine/tangle net	453	469	50.87%		
		Location			
1	1	5	83.33%	5.80	0.055
2	347	377	52.07%		
3	117	96	45.07%		
Tidewater	2	0	0.00%		
		2008			
		Capture			
Captured	301	339			
Recapture	62	57	47.90%	1.03	0.309
		Gear Type			
Hook-and-line	8	8	50.00%	0.15	0.930
Seine net	328	361	52.39%		
Tangle net	27	27	50.00%		
		Location			
1	5	12	70.59%	34.28	0.000
2	212	301	58.67%		
3	146	83	36.24%		

Table 9.–Jolly Seber estimates of abundance (N), survival (ϕ), and recruitment (B) of adult coho salmon at Nakwasina River, 2007.

Week(s)	Dates	$\hat{N}$	$SE(\hat{N})$	$\hat{\phi}$	$SE(\hat{\phi})$	$\hat{B}$	$SE(\hat{B})$
1	09/09 – 10/13	225	81	1.00	0.00	239	16
2	10/14 – 10/20	451	238	0.61	0.12	128	17
3	10/21 – 10/27	397	110	0.52	0.06	186	69
4	10/28 – 11/10	383	51	1.00	0.00	59	215
5	11/11 – 11/17	422	211	0.72	0.05	43	152
6	11/18 – 11/24	346	27	0.66	0.04	4	13
7	11/25 – 12/01	221	16	0.58	0.04	6	4
8	12/02 – 12/08	133	11	0.00	0.00	0	0

Goodness-of-fit tests suggested some potential for capture heterogeneity or handling mortality. Specifically, it appears that fish first captured prior to period 44 and in period 44 were significantly more likely to be seen later in the experiment than fish caught and marked for the first time during period 44 (Table 10, component 1). These test results do not indicate a clear pattern in capture heterogeneity or handling mortality. The overall goodness-of-fit test for homogeneous capture and survival for 2007 has a P-value of 0.26, which indicates that there is not strong evidence of heterogeneity.

Table 10.–Summary of goodness-of-fit tests for homogeneous capture/survival probabilities by tag group in 2007 and 2008. Overall chi-squares are the sum of the individual test statistics.

	Component 1[a]			Component 2[b]		
Week	χ^2	df	P-value	χ^2	df	P-value
2007						
37-41	–	0	–	–	0	–
42	–	0	–	–	0	–
43	0.8279	1	0.3629	–	0	–
44	4.3866	1	0.0362	–	0	–
45	–	0	–	–	0	–
46	0.0177	1	0.8943	0.9398	1	0.3323
47	0.0197	1	0.8884	–	0	–
48	–	0	–	–	0	–
Overall	5.2519	4	0.2624	0.9398	1	0.3323
2008						
23	0.0568	1	0.8117	–	–	–
Overall	0.0568	1	0.8117			

Note: Sample sizes were not sufficient to calculate goodness of fit tests for most periods in 2008.

[a] Test for short-term mortality per Robson (1969).

[b] Test for heterogeneous survival probabilities per Pollock et al. (1990).

Only 6 fish (or 0.6% of the sample) were captured or recovered in section 1while in section 2 76.6% were captured or recovered. In section 3, there were 22.5% of the total captures, and 0.2% were at tidewater (Table 11). In total, 43.4% of the fish inspected for Floy™ tags had either a Floy™ tag or a secondary mark. The probability of capturing a tagged fish was significantly different in section 2 versus section 3 (χ^2 = 91.5, P < 0.0000). The proportions of males and females captured in sections 1, 2, and 3 were significantly different (χ^2 = 5.80 P = 0.055, Table 8), but recapture rates were not significantly different (χ^2 = 1.00 P = 0.318, Table 8).

Table 11.–Results of χ^2 tests for differences in tagged rate between river sections in 2007.

Location	Untagged	Tagged	Total	Percent of total captures by location
		2007		
1	4	2	6	0.6%
2	348	376	724	76.6%
3	181	32	213	22.5%
Tidewater	2		2	0.2%
Total	535	410	945	
Sections 1-3	χ^2=91.5			*P* < 0.000
		2008		
1	17	4	21	2.8%
2	437	94	531	69.7%
3	188	22	210	27.6%
Tidewater				
Total	642	120	762	
Sections 1-3	χ^2=6.10			*P* = 0.047

Length distributions of adult coho salmon captured in 2007 in Nakwasina River were not different between gear type, sex, adipose fin presence, time of capture, or area of capture (Table 12, Figure 4). The average lengths of female and male coho salmon were 632 mm FL (SE = 2.33) and 601 mm FL (SE = 3.90), respectively.

Table 12.–Results of Kolmogorov-Smirnov tests for differences between cumulative length frequencies for adult coho salmon in the Nakwasina River 2007 and 2008.

Component 1	Component 2	n_1	n_2	D_i	*P*-value
		2007			
Male	Female	263	272	0.2674	<0.000
Hook and Line	Seine	21	511	0.1376	0.810
Adipose Clip	No adipose clip	125	410	0.0972	0.311
Section 2	Section 3	348	181	0.0854	0.336
9/13-10/31	11/01-12/05	200	253	0.0543	0.888
		2008			
Male	Female	336	301	0.1725	0.000
Hook and Line	Seine	14	578	0.097	0.999
Adipose Clip	No adipose clip	114	523	0.0674	0.776
Section 2	Section 3	432	188	0.0687	0.553
9/13-10/31	11/01-12/05	128	509	0.0653	0.762

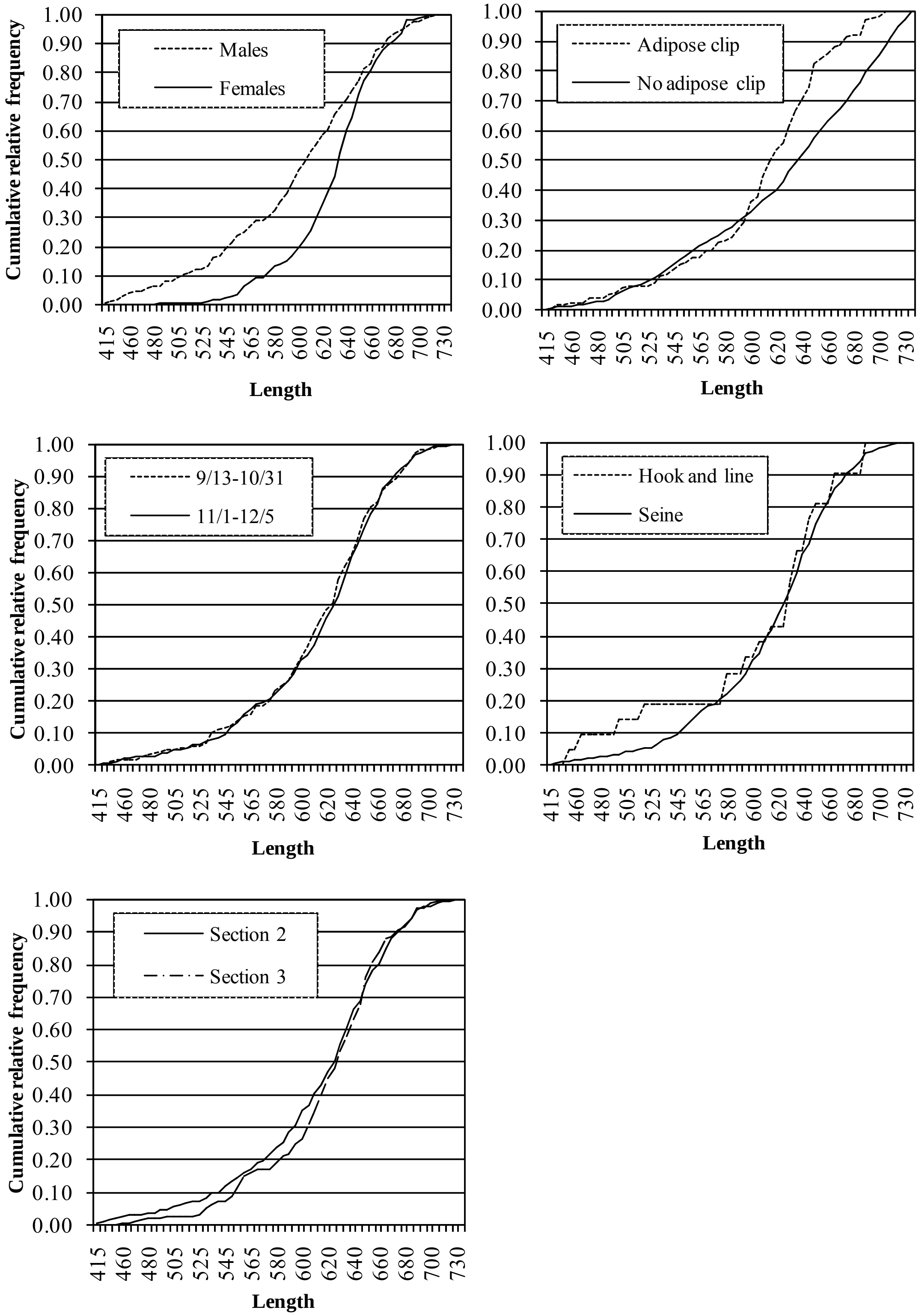

Figure 4.–Cumulative length frequency distributions to test for differences in lengths of captured coho by sex, adipose fin presence, date, gear type, or area in 2007.

Based on an escapement estimate of 1,000, and marine harvest of 1,013, the estimated total run in 2007 was 2,013, ocean survival was 5.3% (SE = 0.8%), and the exploitation rate was 50.3% (SE = 6.4%).

2008

The estimated spawning escapement of coho salmon in Nakwasina River in 2008 was 3,610 fish. A mark recapture experiment was conducted, but failed to obtain the necessary samples needed in order to produce an accurate and unbiased estimation of escapement. Escapement was estimated by applying the expansion factor of 4.3 to the peak foot count of 839.

Sampling resulted in 762 fish captures—642 unique adults were captured and examined and 120 recaptures were made (Table 7; Appendix A3). A total of 104 fish were either sacrificed for their CWTs, or died on capture. Most adult coho captured in Nakwasina River in 2008 were captured with either the beach seine or gillnet, while 16 were captured with hook-and-line (Table 8). Hook-and-line gear was moderately effective at capturing fish but only when water conditions allowed for sighting fish.

Of the sampled fish, 2.8% were captured or recovered in section 1, 69.7% in section 2, and 27.6% in section 3 (Table 11). In total, 16% of the fish inspected for tags either had a tag or a secondary mark. The probability of capturing a tagged fish was significantly different in section 2 versus section 3 (χ^2 = 6.10, P = 0.047). The proportions of males and females captured in sections 1, 2, and 3 were significantly different (χ^2 = 34.28 P < 0.000, Table 8), but recapture rates were not significantly different (χ^2 = 1.03 P = 0.309, Table 8).

Length distributions of adult coho salmon captured in 2008 in Nakwasina River were not different between gear type, sex, adipose fin presence, time of capture, or area of capture (Table 12, Figure 5). The average lengths of female and male coho salmon captured were 672 mm FL (SE = 1.97) and 657 mm FL (SE = 3.37), respectively.

Based on an escapement estimate of 3,610 and a marine harvest of 1,247 fish, the estimated total run in 2008 was 4,857, ocean survival was 8.2%, and the exploitation rate was 25.7%.

FOOT SURVEY COUNTS

Foot survey counts were conducted on Nakwasina River on 3 occasions in 2007 and 2008 (Table 13). In 2007, the peak count was 385 on November 6. In 2008, the peak count was 839 on November 12. These peak counts represent 38.5% and 23.2% of the estimated escapement, respectively.

Table 13.–Stream counts including number of coho counted, date, survey conditions, and percentage of total escapement estimate represented by daily count in Nakwasina River, 2007 and 2008.

Date	Count	Conditions	Percent of total escapement
11/6/2007[a]	385	Visibility normal, tide high, water normal	38.5%
11/13/2007	337	Visibility normal, tide high, water normal	33.7%
11/30/2007	212	Visibility normal, tide high, water normal	21.2%
10/28/2008	561	Visibility normal, water high	15.5%
11/4/2008	703	Visibility normal, tide low, water low	19.5%
11/12/2008[a]	839	Visibility poor, tide high, water low	23.2%

[a] Peak count

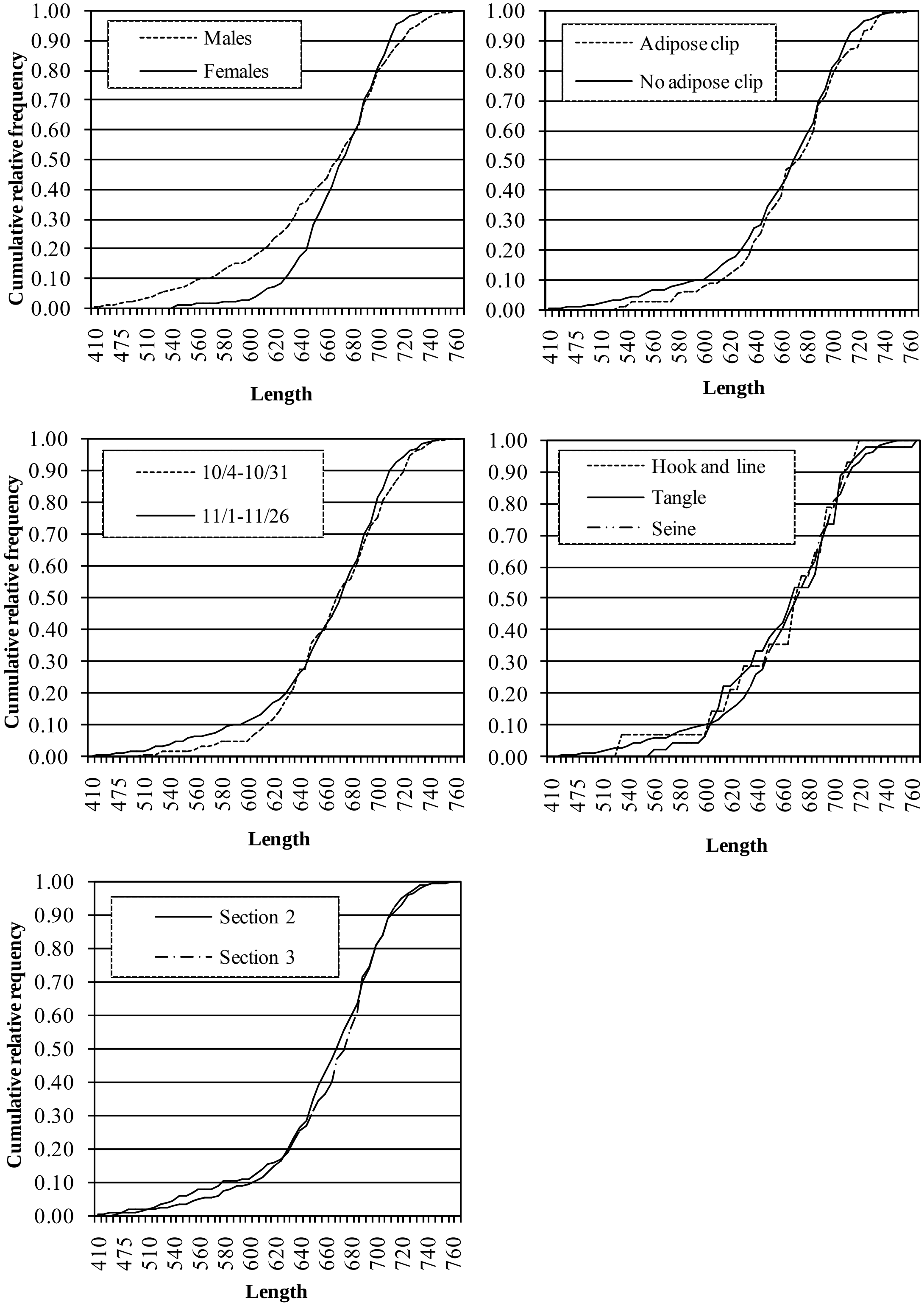

Figure 5.–Cumulative length frequency distributions to test for differences in lengths of captured coho by sex, adipose fin presence, date, gear type, or area in 2008.

DISCUSSION

SMOLT ABUNDANCE AND ADULT HARVEST

The smolt-to-adult survival rates of 5.3% and 8.2% in 2007 and 2008 are lower than the 2000-2006 average (10.0%), but comparable to some of the other systems in the region (Table 14). Because of the low average smolt-to-adult survival rate in Nakwasina River in 2000-2002 (8.7%), extra care was taken in 2006-2007 to insure smolt were given an adequate opportunity to recover and smolt naturally. However, survival remained relatively low in 2007, indicating that Nakwasina River coho smolt-to-adult survival rate may tend toward the lower end of the range observed in Southeast Alaska systems.

Table 14.–Smolt-to-adult survival rate for coho indicator streams around Southeast Alaska 2000–2008.

	Return year									
Stream	2000	2001	2002	2003	2004	2005	2006	2007	2008	Average
Auke Creek	18.5	28.3	26.8	25.0	20.2	16.0	20.3	11.9	24.1	21.3
Chuck Creek				11.9	5.4	9.4	8.3	7.9	5.0	8.0
Berners River	11.8	11.9	19.0	19.1	17.7	8.4	12.8	7.5	15.8	13.8
Taku River	8.1	9.1	13.0	8.8	8.3	8.1	9.9	3.3	7.4	8.4
Ford Arm	12.9	8.4	14.7	17.1	11.9	8.4	10.0	10.3	15.3	12.1
Hugh Smith Lake	6.8	13.5	14.5	13.7	10.4	9.1	6.9	9.0	10.5	10.5
Nakwasina River	6.8	9.5	9.8	11.9	9.9	11.2	11.1	5.3	8.2	9.3
Average	10.8	13.4	16.3	15.4	12.0	10.1	11.3	7.9	12.3	11.9

Condition 1 of an unbiased estimate of smolt abundance required that there was no recruitment to the marked population. Recruitment to Nakwasina River via straying coho salmon from other systems, while possible, is unlikely to present appreciable recruitment to the stock between marking and recovery. Documented coho salmon straying rates vary between populations (Shaul 2010). Straying appears to occur most frequently within hatchery-reared populations and when geographic distance between systems is minimal. However, straying occurrences have been documented over large geographic distances (245 km), and between wild systems. Of the 1,385 marked coho salmon sampled in Nakwasina River between 2000 and 2008, 100% were verified as tag codes originating from Nakwasina River. Likewise, no marked coho salmon originating from Nakwasina have been recovered in any other system. The presence of stray coho salmon reared at Medvejie hatchery is possible, but unlikely given the geographical distance between the 2 sites and the lack of Medevjie origin tag recoveries within Nakwasina River. Additionally, few coho salmon from Medvejie hatchery have been recovered in Salmon Lake, which is much closer to the hatchery release area. The presence of stray coho salmon from adjacent wild stocks is also possible and the true proportion of recruitment into Nakwasina River is unknown.

Vincent-Lang (1993) has shown that coho salmon smolt marked as in this project and handled competently suffer no detectable mortality from the experience, so condition 2 was satisfied. Also, there is no reason to believe that capture rates for adults was influenced by the code on a tag imbedded deep within its cartilage. For these reasons, the differences in recovery rates were most likely due to natural differences in survival rates.

It is unlikely that smolt regenerated the clipped adipose fin that identified the fish as containing a tag, so it is likely that condition 3 was satisfied. In conjunction with tag retention and overnight mortality tests, adipose finclips on smolt were examined. All smolt examined appeared to have good finclips. Also, all adult coho examined had well defined or a complete absence of an adipose fin.

Although the assumption that complete mixing occurred cannot be tested, coho salmon most likely mixed within or across stocks during their extended time (14 months) at sea. In Nakwasina River catches, the fraction of adult coho salmon with marks (missing an adipose fin) did not vary significantly over time in either 2007 (χ^2 = 2.06, P = 0.152) or 2008 (χ^2 = 2.63, P = 0.105; Table 15).

Table 15.–Proportion of recovered Nakwasina River adult coho observed with and without adipose finclips, 2007 and 2008.

2007				2008			
Date	No clip	Clip observed	Tagged portion	Date	No clip	Clip observed	Tagged portion
9/13/2007	1		0.00	10/4/2008	7	2	0.22
10/3/2007	4		0.00	10/27/2008	3	2	0.40
10/10/2007	22	10	0.31	10/30/2008	27	7	0.21
10/11/2007	1	1	0.50	10/31/2008	62	18	0.23
10/16/2007	2	1	0.33	11/5/2008	36	14	0.28
10/17/2007	36	10	0.22	11/6/2008	110	27	0.20
10/23/2007	3	1	0.25	11/13/2008	71	10	0.12
10/24/2007	40	20	0.33	11/18/2008	59	13	0.18
10/25/2007	38	10	0.21	11/20/2008	114	13	0.10
11/5/2007	1	1	0.50	11/25/2008	30	6	0.17
11/6/2007	42	10	0.19	11/26/2008	9	2	0.18
11/7/2007	78	29	0.27	Grand total	528	114	0.178
11/14/2007	2	0	0.00	Oct. 4 - Oct. 31	99	29	
11/19/2007	75	15	0.17	Nov. 1- Nov. 26	429	85	
11/20/2007	25	8	0.24		χ^2 =	2.63	
11/26/2007	31	6	0.16		*P*=	0.105	
12/4/2007	1	1	0.50				
12/5/2007	8	2	0.20				
Grand total	410	125	0.234				
Sep. 13 - Nov 5.	148	54					
Nov. 6 - Dec. 5	262	71					
	χ^2 =	2.06					
	P=	0.152					

Although, smolt-to-adult survival rates for smolt coded-wire-tagged in both 2006 and 2007 were significantly different between smolt tagged in the mainstem of Nakwasina River and those tagged in Bridge Creek, no significant difference in smolt-to-adult survival was detected between small and large size categories of smolt tagged in 2006 and 2007. Based on these results, we concluded that either S2 or S3 was satisfied and a Petersen-type model was appropriate for estimating smolt abundance in 2006 and 2007.

ADULT ESCAPEMENTS IN 2007 AND 2008

During both 2007 and 2008 experiments to estimate adult escapement, tag loss was low (<1%) and sampling rates were high. In 2007, assumptions of the JS experiment were met, and the JS model fit the data. In 2008, a JS experiment was not possible because marking did not occur at the beginning of the run. For this reason, the peak foot count was expanded to estimate escapement.

The fact that the JS estimations were constrained to yield admissible values in 2007 does not necessarily indicate that violation of some of the assumptions occurred and that the estimation model is inappropriate (Schwarz et al. 1993). However, assumptions that all fish have the same survival rate and that all fish have the same probability of capture during each event are not likely to be satisfied in a field experiment such as this one, so potential for bias in the abundance estimate needs to be considered. Differences were found between the fractions of fish carrying marks in upriver and downriver locations (Table 11), indicating that marked and unmarked fish did not mix completely between sampling events. Lack of complete mixing between events can only be mitigated by application of uniform sampling effort across the study area during each event, ensuring similar probabilities of capture for all fish in the experiment during each sampling event. While it is unlikely that equal capture probabilities can be uniformly achieved, field efforts to sample proportional to the perception of fish abundance across the study area are intended to minimize the potential for bias in abundance estimation due to violating this assumption. It is not expected that the survival rate is uniform across all fish in the experiment between sampling events. "Older" fish are expected to have a lower survival rate between events, particularly later in this experiment. While Seber (1982), as cited by Sykes and Botsford (1986), suggests that JS estimates should be relatively unbiased if mark status and mortality are not correlated, Schwarz et al. (1993) demonstrated with simulation that declines in survival of 20% between successive sampling periods after new fish enter the study area can result in overestimates of abundance on the order of 1 standard error of the point estimate. However, if "older" fish are also more susceptible to capture due to declining condition, a negative bias can result which may nearly cancel the positive bias resulting from the survival heterogeneity. While it is expected that fish in this experiment tended to experience lower survival later in their tenure in the study area, it is not likely as well correlated or severe as that simulated by Schwarz et al. (1993). If the escapement estimate is biased due to differential mortality, it is biased high and the magnitude of the bias is within 1 standard error of the estimate.

Although some fish do temporarily emigrate and re-immigrate after being tagged, no data exists to indicate a problem due to fish from other systems temporarily entering the system, being tagged, and then permanently emigrating. Some fish may temporarily emigrate from the study area due to stress associated with handling and tagging and later re-immigrate into the study area. In 2001, a tagged fish with fresh herring in its belly was returned by a fisherman that captured the fish in Nakwasina River. This indicates that some fish do temporarily emigrate and re-immigrate after being tagged. The temporary lack of closure is not likely a significant source of bias. Marking did not appear to significantly affect spawning behavior or long-term movements, as marked fish were observed spawning with or near unmarked fish throughout the study.

In 2007 and 2008, 4 and 17 fish were tagged at tidewater respectively. Of these, no recaptures occurred in section 1 during 2007, while only 1 recapture occurred in 2008. These recovery rates are lower than that of sections 2 and 3 (Table 16). The small sample size of fish captured and tagged in section 1 likely contributed to the differing rates of recovery.

Table 16.–Numbers of fish recaptured by section of original tagging and section of recapture, 2007 and 2008.

	Original tag location			
	1 upstream	2 middle section	3 lower section	Tidewater
2007				
Location of recapture				
Upstream 1			2	
Middle section 2		142	73	
Lower section 3		21	9	
Totals	0	163	84	0
Total number of fish tagged	4	348	181	2
Proportion recovered	0	0.47	0.46	0
2008				
Location of recapture				
Upstream 1		3	1	
Middle section 2	1	57	36	
Lower section 3		18	4	
Totals	1	78	41	0
Total number of fish tagged	17	437	188	0
Proportion recovered	0.06	0.18	0.22	

FOOT SURVEY COUNTS

Nakwasina River is similar to other clearwater streams in the area, and the relationship between the peak observer count and the total escapement is similar to that found in Steep Creek near Juneau, Alaska (20% in Nakwasina River versus 21% in Steep Creek; Jones III and McPherson 1997; McPherson et al. 1996). The ability to count spawning salmon depends on many factors, including the observer, weather, water clarity, canopy cover, pool-to-riffle ratio, the density of fish, the amount of undercut banks, and the ecology, behavior, size, and color of salmon (Jones III 1995).

HARVEST SAMPLING

To assess the adequacy of sampling rates, troll harvests within Southeast Alaska where Nakwasina River coho salmon recovery occurred were examined (Table 17). The sampling rates in 2007 for troll fisheries in the Northwest Quadrant ranged from 8% (District 114) to 37% (Districts 109). In 2008 sampling rates ranged between 25% in District 113 to 35% in District 109. Because not all fisheries were sampled, it is likely that Nakwasina River coho salmon harvest was undetected in some fisheries, which would result in an underestimated total marine harvest. On average, 50% of the harvest of coded wire tagged coho between 1999 and 2008 occur by August 20 and 90% are recovered by September 14.

Nakwasina River coho appear to have later run timing than some of the other streams in the Sitka area. Peak stream counts generally occur in late October or early November in the Nakwasina River, up to a month later than the other 5 index streams in the Sitka area (Table 2, Figure 6). Additionally tag recoveries in marine fisheries occur later than Salmon Lake (Figure 7) by approximately a month. Anecdotal information suggests that Katlian River, near Sitka, exhibits a similar run timing to the Nakwasina River, but most streams in the area follow a return pattern similar to the other 5 index streams in the area.

Table 17.–Numbers of fish harvested and sampled for coded wire tag recovery for districts in which Nakwasina River coho were recovered in 2007 and 2008.

District	Fish harvested	Fish sampled	Proportion sampled
2007			
104	3414	1032	0.30
183	698	188	0.27
116	38152	9141	0.24
109	14,070	5,268	0.37
113	458,736	112,100	0.24
114	24,109	1,818	0.08
189	6,063	562	0.09
Total	502,978	119,748	0.19
2008			
109	11,324	3,993	0.35
113	455,978	112,322	0.25
189	7,681	2,263	0.29
Total	474,983	118,578	0.20

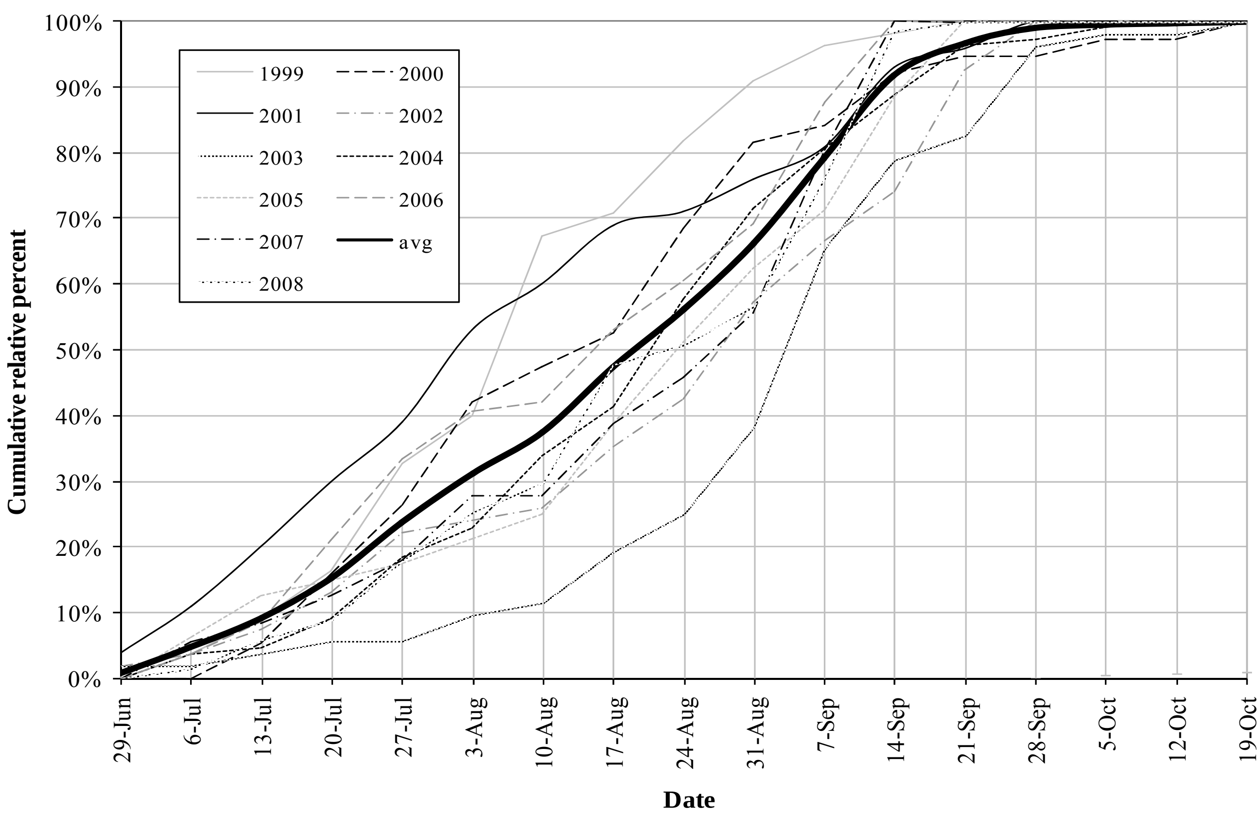

Figure 6.–Cumulative relative percent of Nakwasina River coded wire tag returns by date between 1999 and 2008 in marine sport and commercial fisheries.

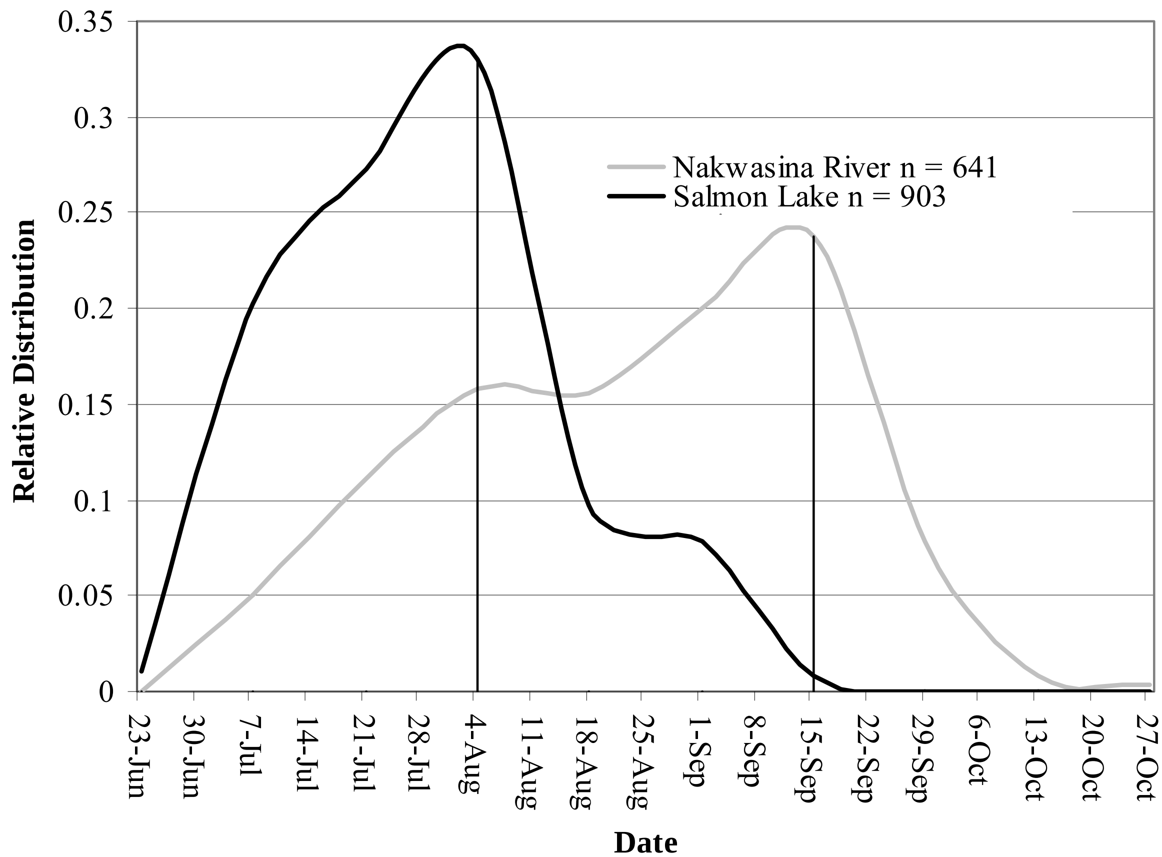

Figure 7.–Relative distribution of coded wire tag recoveries by date from the Nakwasina River and Salmon Lake between 1988 and 2006.

EXPANSION FACTOR

As a tool for estimating escapement without the use of a mark-recapture experiment, an expansion factor was developed for the Nakwasina River. Peak counts were compared to escapement for all years that peak counts and escapement were available except 2004, when a peak count was not available due to poor water conditions. During the 7 years compared, between 2000 and 2006, estimated escapements ranged between 2,000 and 5,698 fish (Table 1, Figure 8). The resulting expansion factor (as described in Appendix A4) was 4.30 (SE = 0.36).

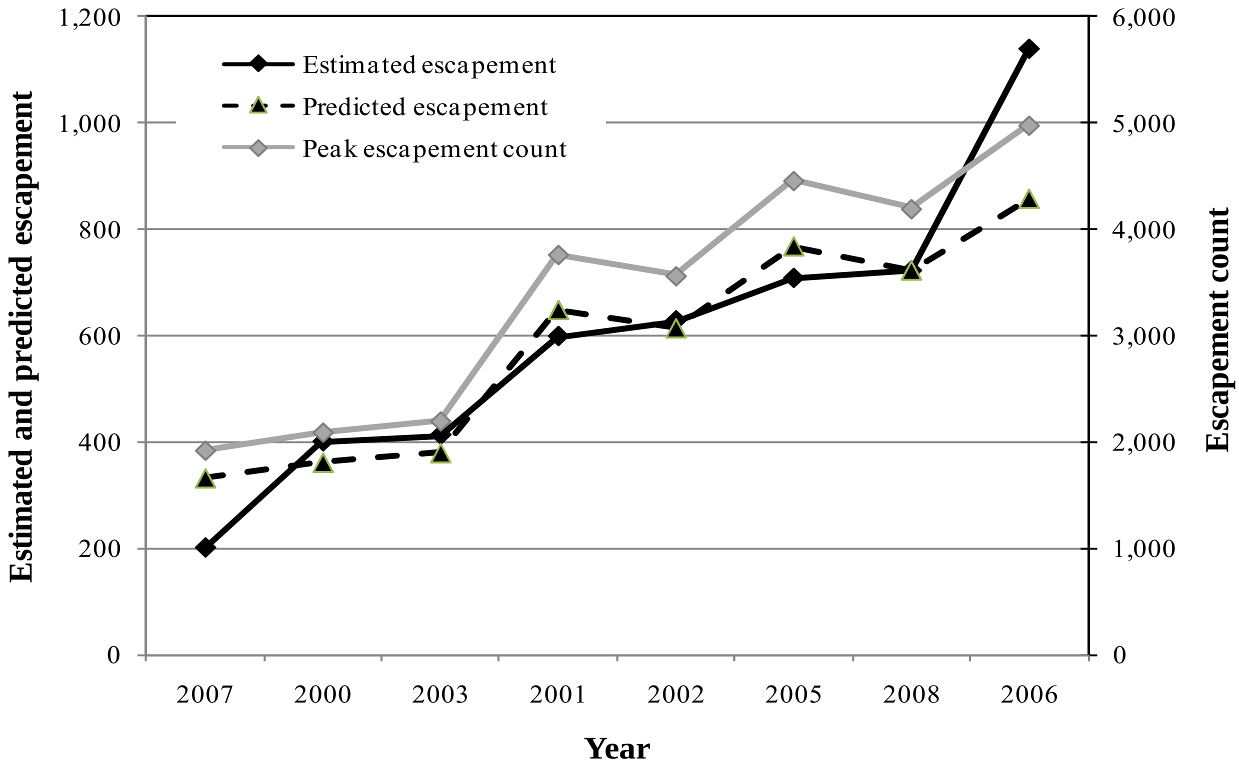

Figure 8.–Estimated escapement, peak counts, and predicted escapement at Nakwasina River, 2000-2008. Predicted escapement was calculated by applying an expansion factor of 4.30 to peak escapement count. In 2008 predicted and estimated escapement were based on an expansion of the peak foot count.

RECOMMENDATIONS

CONTINUATION OF PROJECT

This project should continue for the estimation of escapement, harvest, smolt abundance, survival, and exploitation. Nakwasina River is the only non-lake system which is used as a full indicator stock, in the outside waters of northern Southeast Alaska (Shaul et al. 2008). As such, it is important to the region to serve as an indicator for this specific, non-lake stream habitat. In order to identify trends in abundance, survival and exploitation a long term data series is needed. Nakwasina River represents the most complete coho data set in the Sitka area and the continuation of this project would yield the information necessary to establish a biological escapement goal. Additions to the dataset will allow a more comprehensive understanding of variations through time and enable appropriate management action. In addition, the expansion factor that was developed to apply towards Nakwasina River foot surveys will increase in confidence as the dataset grows.

DEVELOPMENT OF ADDITIONAL EXPANSION FACTORS

The development of additional expansion factors for the other 4 coho index streams within the Sitka area may provide the opportunity to estimate trends in abundance and the refinement of escapement goals. Currently, peak counts in the Sitka area are only useful as an index of abundance, but it is unknown how these counts relate to actual escapements. Coho salmon in Southeast Alaska frequently exhibit prolonged run timing during the fall and the return timing is often correlated with high water events, making peak foot surveys problematic. The use of open population mark-recapture experiments may be the only way to successfully estimate abundance in these conditions. Comparing peak stream counts on other index systems to an estimated escapement, derived from an open population mark-recapture experiment, would provide a expansion factor that could be used not only to estimate escapement, but would also allow the estimation of escapement for prior years.

TAGGING

In future tagging events, extra care should be taken to ensure that any potential effects of tagging are minimized. Recommendations for future tagging include 1) releasing smolt in side tributaries with extensive available rearing habitat as opposed to mainstem areas with higher velocities; 2) minimizing transport distances by centralizing the tagging and holding site; 3) returning tagged smolt to locations near their capture site; 4) tagging and sampling all fish within 48 hours of capture to ensure fish are not held for periods greater than 72 hours, including overnight mortality testing; and 5) estimating the true contribution and survival of Bridge Creek smolt in the Nakwasina adult escapement. This may be accomplished by installing a weir on Bridge Creek to count migrating smolt, or conducting a mark-recapture experiment to estimate the number of smolt in Bridge Creek prior to the migration.

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APPENDIX A

Appendix A1.–Brood year, age classes and lengths of coho by year sampled in the Nakwasina River, 2004-2008.

	Brood year	2005	2004	2005	2004	2003	2004	2003	2003	2002	2002	2001	2002	2001	2000
	Sample year	2008		2007			2006				2005		2004		
	Age class	1.1	2.1	1.0	1.1	2.1	1.0	2.0	1.1	2.1	1.1	2.1	1.0	1.1	2.1
Females	Sample size	211	3	-	181	4	-	-	241	7	247	4	-	332	4
	Percent	98.6%	1.4%	-	97.8%	2.2%	-	-	97.2%	2.8%	98.4%	1.6%	-	98.8%	1.2%
	SE	0.8%	0.8%	-	1.1%	1.1%	-	-	1.1%	1.1%	0.8%	0.8%	-	0.6%	0.6%
	Mean length	672	662	-	630	663	-	-	650	664	639	673	-	640	615
	SE	2.3	11.7	-	2.9	10.9	-	-	2.3	20.3	2.2	24.4	-	2.2	26.8
Males	Sample size	259	-	5	180	2	15	1	388	5	373	10	20	488	7
	Percent	100.0%	-	2.7%	96.3%	1.1%	3.7%	0.2%	94.9%	1.2%	97.4%	2.6%	3.9%	94.8%	1.4%
	SE	0.0%	-	0.8%	0.8%	0.8%	0.9%	0.2%	1.1%	0.5%	0.8%	0.8%	0.9%	1.0%	0.5%
	Mean length	659	-	326	605	648	303	320	630	588	622	620	327	626	636
	SE	3.8	-	8.0	4.4	27.5	10.3	-	3.4	22.7	2.2	24.3	5.2	2.6	24.8
All fish	Sample size	470	3	5	361	6	15	1	629	12	620	14	20	820	11
	Percent	99.4%	0.63%	1.3%	97.0%	1.6%	2.3%	0.2%	95.7%	1.8%	97.8%	2.2%	2.4%	96.4%	1.3%
	SE	0.4%	0.4%		0.7%	0.7%	0.6%	0.2%	0.8%	0.5%	0.6%	0.6%	0.5%	0.6%	0.4%
	Mean length	666	662	326	618	658	303	320	638	632	629	623	327	632	629
	SE	2.4	11.7	8.0	2.7	10.4	10.3	-	2.3	18.3	2.2	18.2	5.2	1.8	18.0

Appendix A2.–Recoveries of coded wire tags originating from Nakwasina River coho salmon in 2007 and 2008.

2007										
Head	Tag code	Gear class	Date (CWT)	Stat week	Quadrant	District	Sub-district	Length	Survey site	Sample
Random Recoveries										
540459	41147	PURSE	8/7/2007	32	NW	113	95	615	EXCURSION INLET	7100069
325840	41146	PURSE	7/16/2007	29	SW	104	20	470	KETCHIKAN	7066413
350173	41145	TROLL	9/4/2007	36	NE	109		475	SITKA	7037541
312332	41145	TROLL	7/9/2007	28	NW	113	91	495	SITKA	7036943
312273	41145	TROLL	7/10/2007	28	NW			500	SITKA	7036985
99200	41145	TROLL	7/10/2007	28	NW			520	HOONAH	7110076
99670	41145	TROLL	8/9/2007	32	NW			601	HOONAH	7110133
58287	41146	TROLL	7/28/2007	30	NW			540	PELICAN	7010164
58349	41146	TROLL	8/1/2007	31	NW	116	12	510	PELICAN	7010173
99646	41146	TROLL	8/6/2007	32	NW	116	12	562	HOONAH	7110124
540471	41146	TROLL	8/9/2007	32	NW			635	EXCURSION INLET	7100075
99689	41146	TROLL	8/11/2007	32	NW			550	HOONAH	7110137
519867	41147	TROLL	7/12/2007	28	NW	183	10	525	YAKUTAT	7140107
522927	41147	TROLL	7/16/2007	29	NW	113	91	550	PELICAN	7010126
540406	41147	TROLL	7/29/2007	31	NW			540	EXCURSION INLET	7100053
327097	41147	TROLL	8/1/2007	31	NW	113		480	SITKA	7037218
99667	41147	TROLL	8/9/2007	32	NW	114	21	532	HOONAH	7110130
99693	41147	TROLL	8/11/2007	32	NW			505	HOONAH	7110137
326490	41145	TROLL	8/19/2007	34	NW	113		585	SITKA	7037382
327845	41145	TROLL	8/22/2007	34	NW			515	SITKA	7037439
349526	41145	TROLL	8/30/2007	35	NW	113	62	635	SITKA	7037510
327258	41145	TROLL	9/4/2007	36	NW	113	62	510	SITKA	7037535
58836	41145	TROLL	9/9/2007	37	NW	113	91	560	PELICAN	7010250
525983	41145	TROLL	9/10/2007	37	NW	189	30	630	YAKUTAT	7140200
350409	41145	TROLL	9/12/2007	37	NW	114	21	540	SITKA	7037559
58960	41145	TROLL	9/14/2007	37	NW			605	PELICAN	7010268
541037	41145	TROLL	9/15/2007	37	NW	113	91	530	PELICAN	7010278
541043	41145	TROLL	9/15/2007	37	NW	113	91	570	PELICAN	7010278
96955	41145	TROLL	9/18/2007	38	NW			531	HOONAH	7110246
96962	41145	TROLL	9/18/2007	38	NW			575	HOONAH	7110246
96990	41145	TROLL	9/18/2007	38	NW			575	HOONAH	7110252
54064	41145	TROLL	9/18/2007	38	NW			591	HOONAH	7110252
350977	41145	TROLL	9/21/2007	38	NW	113	91	505	SITKA	7037633
349074	41145	TROLL	8/21/2007	34	NW	113		520	SITKA	7037435
327896	41146	TROLL	8/22/2007	34	NW			590	SITKA	7037471
58750	41146	TROLL	8/30/2007	35	NW			480	PELICAN	7010233
96777	41146	TROLL	9/10/2007	37	NW			630	HOONAH	7110223
350403	41146	TROLL	9/12/2007	37	NW	114	21	620	SITKA	7037559
58979	41146	TROLL	9/14/2007	37	NW	113	91	605	PELICAN	7010270
541028	41146	TROLL	9/15/2007	37	NW	113	91	560	PELICAN	7010277
350946	41146	TROLL	9/20/2007	38	NW			490	SITKA	7037623
350982	41146	TROLL	9/21/2007	38	NW	113	91	600	SITKA	7037633

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Head	Tag code	Gear class	Date (CWT)	Stat week	Quadrant	District	Sub-district	Length	Survey site	Sample
					Random Recoveries					
54073	41146	TROLL	9/21/2007	38	NW	113		656	HOONAH	7110253
350834	41146	TROLL	9/21/2007	38	NW	113		665	SITKA	7037626
540591	41147	TROLL	8/24/2007	34	NW			570	EXCURSION INLET	7100105
349556	41147	TROLL	8/28/2007	35	NW			585	SITKA	7037507
58743	41147	TROLL	8/30/2007	35	NW			550	PELICAN	7010231
349828	41147	TROLL	9/4/2007	36	NW	113	62	565	SITKA	7037517
327259	41147	TROLL	9/4/2007	36	NW	113	62	600	SITKA	7037535
58792	41147	TROLL	9/4/2007	36	NW	113	91	600	PELICAN	7010242
96719	41147	TROLL	9/4/2007	36	NW			573	HOONAH	7110215
349894	41147	TROLL	9/5/2007	36	NW	113	11	455	SITKA	7037521
58835	41147	TROLL	9/9/2007	37	NW	113	91	640	PELICAN	7010251
58913	41147	TROLL	9/10/2007	37	NW	114	21	515	PELICAN	7010262
350457	41147	TROLL	9/13/2007	37	NW	113	62	520	SITKA	7037567
58947	41147	TROLL	9/13/2007	37	NW	113	91	560	PELICAN	7010266
350620	41147	TROLL	9/14/2007	37	NW	113	62	555	SITKA	7037581
541103	41147	TROLL	9/20/2007	38	NW			620	PELICAN	7010282
541102	41147	TROLL	9/20/2007	38	NW			700	PELICAN	7010282
540163	41147	TROLL	9/21/2007	38	NW	113	91	620	JUNEAU	7046071
350682	41147	TROLL	9/21/2007	38	NW			620	SITKA	7037634
349065	41147	TROLL	8/21/2007	34	NW	113		530	SITKA	7037434
315696	41146	TROLL	9/11/2007	37				640	SITKA	7037550
349978	41147	TROLL	9/11/2007	37				590	SITKA	7037551
83442	41145	SPORT	7/26/2007	30	NW	113	62	670	SITKA	7035393
322636	41145	SPORT	7/28/2007	30	NW	113	45	515	SITKA	7035357
324976	41145	SPORT	8/22/2007	34	NW	113	31	520	SITKA	7035579
69736	41146	SPORT	8/25/2007	34	NW	113	91	475	ELFIN COVE	7025046
324987	41146	SPORT	8/28/2007	35	NW	113	61	645	SITKA	7035602
					Select Recoveries					
900653	41145	TROLL	9/12/2007	37	NW	154			SITKA	7039992
900955	41146	TROLL	9/18/2007	38	NW	113	91		SITKA	7039978
254895	41147		7/31/2007	31	NW	113	41		SITKA	7035403
					2008					
					Random Recoveries					
333471	41307	TROLL	7/29/2008	31	NE	109	61	580	SITKA	8037380
329345	41307	TROLL	7/6/2008	28	NW	113	21	535	SITKA	8037110
330963	41307	TROLL	7/15/2008	29	NW	113		550	SITKA	8037227
331155	41307	TROLL	7/15/2008	29	NW			540	SITKA	8037234
331458	41307	TROLL	7/23/2008	30	NW	113		570	SITKA	8037303
354411	41307	TROLL	7/24/2008	30	NW			591	HOONAH	8110121
354429	41307	TROLL	7/29/2008	31	NW	113		576	HOONAH	8110124
354507	41307	TROLL	7/30/2008	31	NW			619	HOONAH	8110129
333485	41307	TROLL	7/31/2008	31	NW	113	45	640	SITKA	8037390

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Head	Tag code	Gear class	Date (CWT)	Stat week	Quadrant	District	Sub-district	Length	Survey site	Sample
					Random Recoveries					
331353	41307	TROLL	8/4/2008	32	NW	113	21	630	SITKA	8037438
540697	41307	TROLL	8/8/2008	32	NW			605	EXCURSION INLET	8100073
354270	41308	TROLL	7/13/2008	29	NW			646	HOONAH	8110107
331723	41308	TROLL	8/2/2008	31	NW	113	21	600	SITKA	8037433
331677	41309	TROLL	8/1/2008	31	NW	113	21	535	SITKA	8037409
354575	41309	TROLL	8/3/2008	32	NW			632	HOONAH	8110138
357048	41307	TROLL	8/10/2008	33	NW	113	45	610	SITKA	8037489
354713	41307	TROLL	8/18/2008	34	NW			630	HOONAH	8110161
357384	41307	TROLL	8/19/2008	34	NW	113	41	620	SITKA	8037594
357357	41307	TROLL	8/19/2008	34	NW	113	81	545	SITKA	8037579
357447	41307	TROLL	8/19/2008	34	NW	113	41	660	SITKA	8037605
357948	41307	TROLL	8/22/2008	34	NW	113	45	625	SITKA	8037668
332133	41307	TROLL	8/22/2008	34	NW	113	61	610	SITKA	8037678
332404	41307	TROLL	9/3/2008	36	NW			655	SITKA	8037731
332403	41307	TROLL	9/3/2008	36	NW			625	SITKA	8037731
70710	41307	TROLL	9/5/2008	36	NW	189	30	655	YAKUTAT	8146128
355235	41307	TROLL	9/8/2008	37	NW	113	91	665	JUNEAU	8046081
355407	41307	TROLL	9/8/2008	37	NW	113	91	600	JUNEAU	8046081
354960	41307	TROLL	9/8/2008	37	NW	113	91	701	HOONAH	8110215
354984	41307	TROLL	9/9/2008	37	NW			689	HOONAH	8110219
332641	41307	TROLL	9/11/2008	37	NW			560	SITKA	8037776
332723	41307	TROLL	9/12/2008	37	NW			600	SITKA	8037802
332704	41307	TROLL	9/12/2008	37	NW			650	SITKA	8037802
332667	41307	TROLL	9/12/2008	37	NW			650	SITKA	8037778
71265	41307	TROLL	9/14/2008	38	NW	189	30	655	YAKUTAT	8146153
355155	41307	TROLL	9/15/2008	38	NW			644	HOONAH	8110226
355530	41307	TROLL	9/16/2008	38	NW	113	91	710	JUNEAU	8046094
355189	41307	TROLL	9/16/2008	38	NW			679	HOONAH	8110236
355160	41307	TROLL	9/16/2008	38	NW			653	HOONAH	8110228
332877	41307	TROLL	9/17/2008	38	NW			650	SITKA	8037813
337363	41307	TROLL	9/18/2008	38	NW	113	45	630	SITKA	8037810
355177	41307	TROLL	9/18/2008	38	NW	189	30	711	HOONAH	8110235
337047	41307	TROLL	9/19/2008	38	NW				SITKA	8037816
337035	41307	TROLL	9/19/2008	38	NW				SITKA	8037816

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Appendix A2.–Page 4 of 4.

Head	Tag code	Gear class	Date (CWT)	Stat week	Quadrant	District	Sub-district	Length	Survey site	Sample
					Random Recoveries					
337383	41307	TROLL	9/19/2008	38	NW				SITKA	8037816
337071	41307	TROLL	9/19/2008	38	NW				SITKA	8037816
357375	41308	TROLL	8/19/2008	34	NW	113	45	665	SITKA	8037593
357769	41308	TROLL	8/22/2008	34	NW	113	31	645	SITKA	8037655
355054	41308	TROLL	8/31/2008	36	NW			701	HOONAH	8110199
332472	41308	TROLL	9/8/2008	37	NW	113	45	680	SITKA	8037755
332660	41308	TROLL	9/12/2008	37	NW			660	SITKA	8037778
332686	41308	TROLL	9/12/2008	37	NW			605	SITKA	8037778
332857	41308	TROLL	9/17/2008	38	NW			680	SITKA	8037813
332601	41309	TROLL	9/9/2008	37	NW	113	91	640	SITKA	8037767
332710	41309	TROLL	9/12/2008	37	NW			640	SITKA	8037802
540751	41307	PURSE	8/12/2008	33	NW	113	40	630	EXCURSION INLET	8100077
540797	41307	PURSE	8/19/2008	34	NW	113	40	535	EXCURSION INLET	8100086
259391	41307	SPORT	8/25/2008	35	NW	113	45	620	SITKA	8035185
259384	41308	SPORT	8/17/2008	34	NW	113	71	650	SITKA	8035166
322437	41308	SPORT	8/30/2008	35	NW	113	61	640	SITKA	8035191
259382	41309	SPORT	8/17/2008	34	NW	113	71	670	SITKA	8035166
					Select Recoveries					
322349	41308	SPORT	8/9/2008	32	NW	113	61		SITKA	8035150
900089	41307	TROLL	8/10/2008	33	NW	116	13		SITKA	8039993
901036	41307	TROLL	8/22/2008	34	NW	113	41		SITKA	8039979
900529	41307	TROLL	9/16/2008	38	NW	113	41		SITKA	8039987
900519	41307	TROLL	9/16/2008	38	NW	113	41		SITKA	8039987
321741	41307	TROLL	9/21/2008	39	NW	114	21	570	JUNEAU	8040502
307361	41307	PURSE	8/7/2008	32	NW	113		470	PETERSBURG	8056585

Appendix A3.–Capture and recovery data from the Nakwasina River coho salmon mark-recapture study, 2007 and 2008, by section and date.

Week #	Location	Original captures	Recaptures	Total captures	Proportion (Floy) tagged	Original captures	Recaptures	Total captures	Proportion (Floy) tagged
		2007				2008			
37	2	1		1	0.00				
40	2	1		1	0.00	9		9	0.00
	3	1		1	0.00			0	
	TW	2		2	0.00			0	
41	2	20		20	0.00			0	
	3	14		14	0.00			0	
42	1			0				0	
	2	24	1	25	0.04			0	
	3	25	2	27	0.07			0	
43	1	2		2	0.00			0	
	2	57	9	66	0.14			0	
	3	53	4	57	0.07			0	
44	1			0				0	
	2			0		84		84	0.00
	3			0		35		35	0.00
45	1			0		6		6	0.00
	2	108	33	141	0.23	181	15	196	0.08
	3	53	5	58	0.09			0	
46	1	2	2	4	0.50			0	
	2			0				0	
	3			0		81	6	87	0.07
47	1			0				0	
	2	90	82	172	0.48	127	61	188	0.32
	3	33	21	54	0.39	72	16	88	0.18
48	1			0		11	4	15	0.27
	2	37	132	169	0.78	36	18	54	0.33
49	2	10	119	129	0.92			0	
	3	2		2	0.00			0	
	Grand total	535	410	945	0.43	642	120	762	0.16

The expansion factor provides a means of predicting escapement in years where only an index count of the escapement is available, i.e. no weir counts or mark-recapture experiments were conducted. The expansion factor is the average over several years of the ratio of the escapement estimate (or weir count) to the index count.

Systems where escapement is known

On systems where escapement can be completely enumerated with weirs or other complete counting methods, the expansion factor is an estimate of the expected value of the "population" of annual expansion factors (π's) for that system:

$$\bar{\pi} = \frac{\sum_{y=1}^{k} \pi_y}{k} \tag{1}$$

where $\pi_y = N_y / C_y$ is the observed expansion factor in year *y*, N_y is the known escapement in year *y*, C_y is the index count in year *y*, and *k* is the number of years for which these data are available to calculate an annual expansion factor.

The estimated variance for expansion of index counts needs to reflect two sources of uncertainty for any predicted value of π, (π_p). First is an estimate of the process error (*var*(π); the variation across years in the π's, reflecting, for example, weather or observer-induced effects on how many fish are counted in a survey for a given escapement. Second is the sampling variance of $\bar{\pi}$ (*var* ($\bar{\pi}$)), which will decline as we collect more data pairs.

The variance for prediction will be estimated (Neter et al. 1990):

$$v\hat{a}r(\pi_p) = v\hat{a}r(\pi) + v\hat{a}r(\bar{\pi}) \tag{2}$$

where:

$$v\hat{a}r(\pi) = \frac{\sum_{y=1}^{k} (\pi_y - \bar{\pi})^2}{k-1} \tag{3}$$

and:

$$v\hat{a}r(\bar{\pi}) = \frac{\sum_{y=1}^{k} (\pi_y - \bar{\pi})^2}{k(k-1)} \tag{4}$$

such that:

$$v\hat{a}r(\pi_p) = \frac{\sum_{y=1}^{k} (\pi_y - \bar{\pi})^2}{k-1} + \frac{\sum_{y=1}^{q} (\pi_y - \bar{\pi})^2}{k(k-1)} \tag{5}$$

Systems where escapement is estimated

On systems where escapement is estimated, the expansion factor is an estimate of the expected value of the "population" of annual expansion factors (π's) for that system:

$$\bar{\pi} = \frac{\sum_{y=1}^{k} \hat{\pi}_y}{k} \tag{6}$$

where $\hat{\pi}_y = \hat{N}_y / C_y$ is the estimate of the expansion factor in year y, $\hat{N}_y$ is the estimated escapement in year y, and other terms are as described above.

The variance for prediction will again be estimated:

$$v\hat{a}r(\pi_p) = v\hat{a}r(\pi) + v\hat{a}r(\bar{\pi}) \tag{7}$$

The estimate of $var(\pi)$ should again reflect only process error. Variation in $\hat{\pi}$ across years, however, represents process error **plus** measurement error within years (e.g. the mark-recapture induced error in escapement estimation) and is described by the relationship (Mood et al. 1974):

$$V(\hat{\pi}) = V[E(\hat{\pi})] + E[V(\hat{\pi})] \tag{8}$$

This relationship can be rearranged to isolate process error, that is:

$$V[E(\hat{\pi})] = V[\hat{\pi}] - E[V(\hat{\pi})] \tag{9}$$

An estimate of $var(\pi)$ representing only process error therefore is:

$$v\hat{a}r(\pi) = v\hat{a}r(\hat{\pi}) - \frac{\sum_{y=1}^{k} v\hat{a}r(\hat{\pi}_y)}{k} \tag{10}$$

Where $v\hat{a}r(\hat{\pi}_y) = v\hat{a}r(\hat{N}_y) / C_y^2$ and $v\hat{a}r(\hat{N}_y)$ is obtained during the experiment when N_y is estimated. We can calculate:

$$v\hat{a}r(\hat{\pi}) = \frac{\sum_{y=1}^{k} (\hat{\pi}_y - \bar{\pi})^2}{k-1} \tag{11}$$

and we can estimate $var(\bar{\pi})$ similarly to as we did above:

$$v\hat{a}r(\bar{\pi}) = \frac{\sum_{y=1}^{k} (\hat{\pi}_y - \bar{\pi})^2}{k(k-1)} \tag{12}$$

where both process and measurement errors need to be included.

For large k (k > 30), equations (11) and (12) provide reasonable parameter estimates, however for small k the estimates are imprecise and may result in negative estimates of variance when the results are applied as in equation (7).

Because k is typically < 10, we will estimate $var(\hat{\pi})$ and $var(\overline{\pi})$ using parametric bootstrap techniques Efron and Tibshirani 1993. The sampling distributions for each of the $\hat{\pi}_y$ are modeled using Normal distributions with means $\hat{\pi}_y$ and variances $v\hat{a}r(\hat{\pi}_y)$. At each bootstrap iteration, a bootstrap value $\hat{\pi}_{y(b)}$ is drawn from each of these Normal distributions and the bootstrap value $\hat{\pi}_{(b)}$ is randomly chosen from the k values of $\hat{\pi}_{y(b)}$. Then, a bootstrap sample of size k is drawn from the k values of $\hat{\pi}_{y(b)}$ by sampling with replacement, and the mean of this bootstrap is the bootstrap value $\overline{\pi}_{(b)}$. This procedure is repeated B = 1,000,000 times. We can then estimate $var(\hat{\pi})$ using:

$$v\hat{a}r_B(\hat{\pi}) = \frac{\sum_{b=1}^{B}(\hat{\pi}_{(b)} - \overline{\hat{\pi}_{(b)}})^2}{B-1} \tag{13}$$

where:

$$\overline{\hat{\pi}_{(b)}} = \frac{\sum_{b=1}^{B}\hat{\pi}_{(b)}}{B} \tag{14}$$

And we can calculate $var_B(\overline{\pi})$ using equations (13) and (14) with appropriate substitutions. The variance for prediction is then estimated:

$$v\hat{a}r(\pi_p) = v\hat{a}r_B(\hat{\pi}) - \frac{\sum_{y=1}^{k}\hat{\mathrm{var}}(\hat{\pi}_y)}{k} + v\hat{a}r_B(\overline{\pi}) \tag{15}$$

As the true sampling distributions for the $\hat{\pi}_y$ are typically skewed right, using a Normal distribution to approximate these distributions in the bootstrap process will result in estimates of $var(\hat{\pi})$ and $var(\overline{\pi})$ that are biased slightly high, but simulation studies using values similar to those realized for this application indicated that the bias in equation (15) is < 1%.

Predicting Escapement

In years when an index count (C_p) is available but escapement (N_p) is not known, it can be predicted:

$$\hat{N}_p = \overline{\pi}\, C_p \tag{16}$$

and:

$$v\hat{a}r(\hat{N}_p) = C_p^2 v\hat{a}r(\pi_p) \tag{17}$$

Appendix A5.–Data files used to estimate parameters of the Nakwasina River coho population, 2006 through 2008.

Data File[a]	Description
2007-2008_Adult_CWT_Recoveries.xls	Recovery information from 2007-2008 coded wire tag recoveries in Southeast Alaska.
Nakwasina_River_2007_8_M-R_and_CWT.xls	Mark, recapture, and coded wire tag recovery information from fish captured in Nakwasina River in 2007.
2007-2008AdultAWL.xls	Age and length Information including summary statistics of adult coho captured in Nakwasina River in 2007-2008.
2006-2007_smolt_AWL_data.xls	2006 and 2007 smolt raw data including summaries of analyzed data.

[a] Data files were archived at and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1599.